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Mineral Analyses of Some Ordovician Rocks from Carnarvonshire.

Introduction.

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VERY little work seems to have been done on the petrology of the rarer constituents of the older Palaeozoic sediments and their associated igneous rocks, partly no doubt on account of the extra amount of work entailed in crushing these extremely hard compact rocks, and partly owing to the comparative paucity of the "heavy" residues obtained, which give small reward for the energy expended. Such work, however, is highly important as indicating further sources of supply, to which workers on the petrology of the newer rocks may look, and it may be here emphasized that Wales has unfortunately suffered neglect in this respect. It is to help remedy this defect that the present paper is put forward.

The rocks examined have been collected at various times since 1923 from north-east Carnarvonshire, and with the possible exception of those from west of the Aber Valley, are all of Ordovician age, and include typical "greenstones", dolerites, lavas, tuffs, and grits. In addition, examination of superficial deposits has thrown some light on the effect of the Glacial Period, and has sometimes afforded a check on the crushed rocks.

Mineralogy.

(a) *Treatment.*

The usual methods of separation by bromoform were followed, and panning, sifting, electromagnetic, acid and microchemical treatment applied where necessary. Two methods of crushing were adopted, and in a few cases the second crushed sample was found to yield an extra mineral species, and in any case yielded a check upon the first determination. More than one specimen was examined from each locality and the results shown in Table II have been selected as representative examples from over 125 rocks so investigated.

Several difficulties arise in the work. The rocks are sometimes so compact as to defy initial fracture except under the influence of a sledge-hammer, and the hard blows necessitated must frequently result in partial or total obliteration of some of the species. Granites and sandstones are friable by comparison, and the results therefore more certain. Again, the crushed rocks always contain a very large proportion of decomposed minerals, amongst which iron ores, pyrite, chloritized felspars, chlorite, and much opaque white material are most common. Indeed, these constituents may make up 90 per cent of the heavy residue. Very frequently compound grains sink in the bromoform, and the identity of the individual minerals therefore is rendered extremely difficult to determine.

(*b*) *Description of Minerals.*

Table I shows only the characteristic minerals of each rock type thus obtained. Certain minerals not shown in the table are of very restricted distribution. Thus biotite, diallage, and hornblende occur in the basic sills of Foel Lwyd. White mica is almost invariably altered to chlorite, and leucoxene has frequently suffered partial or complete alteration to sphene. Mispickel has been observed in cream-coloured tuffs on Tal y Fan. Galena and sphalerite occur in the lodes at the Trecastell lead-zinc mine. Enstatite and prehnite are found in the Penmaenmawr rock as well as axinite, pectolite, zoisite, and talc in smaller quantity on Graig Lwyd.[1] Similarly kelyphitic actinolite and a colourless amphibole are present in the basic sills, but will not adequately survive the crushing process. In the grits may be found much opaque whitish material, some of which is probably leucoxene. A grain of monazite has been recognized from the coastal drift.

The characteristic minerals obtained from the various types of rock examined are described below.

(1) *Basic sills, diabases, and " greenstones ".*

Pyrite is a secondary mineral of common occurrence and is usually found as irregularly-shaped grains averaging ·4 mm. Larger massive forms occur, and granular pyrite is present in pisolitic iron ore from south-east of Maes y Gaer, Aber. Interesting crystals were obtained from a crushed rock from the mine adit a quarter of a mile east of Maes y Gaer. The heavy residue of this rock consists totally of a mass of pyrite cubes ranging from ·09 to ·5 mm. About 40 per cent are perfectly formed separate crystals with well-marked striae, and the rest fractured crystals. A few show secondary enlargement, the faces of the secondary growth being parallel to the corresponding faces upon which they grew. Only a few limonite pseudomorphs were found in this rock. This is in striking contrast with the ragged pyrite from a similar sill in the same district a

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[1] H. C. Sargent, " Notes on the Petrology of Penmaenmawr Mountain," *Proc. Lpl. Geol. Soc.*, vol. xiv, 1924, pp. 85–94, and pt. ii, 1925, pp. 123–34.

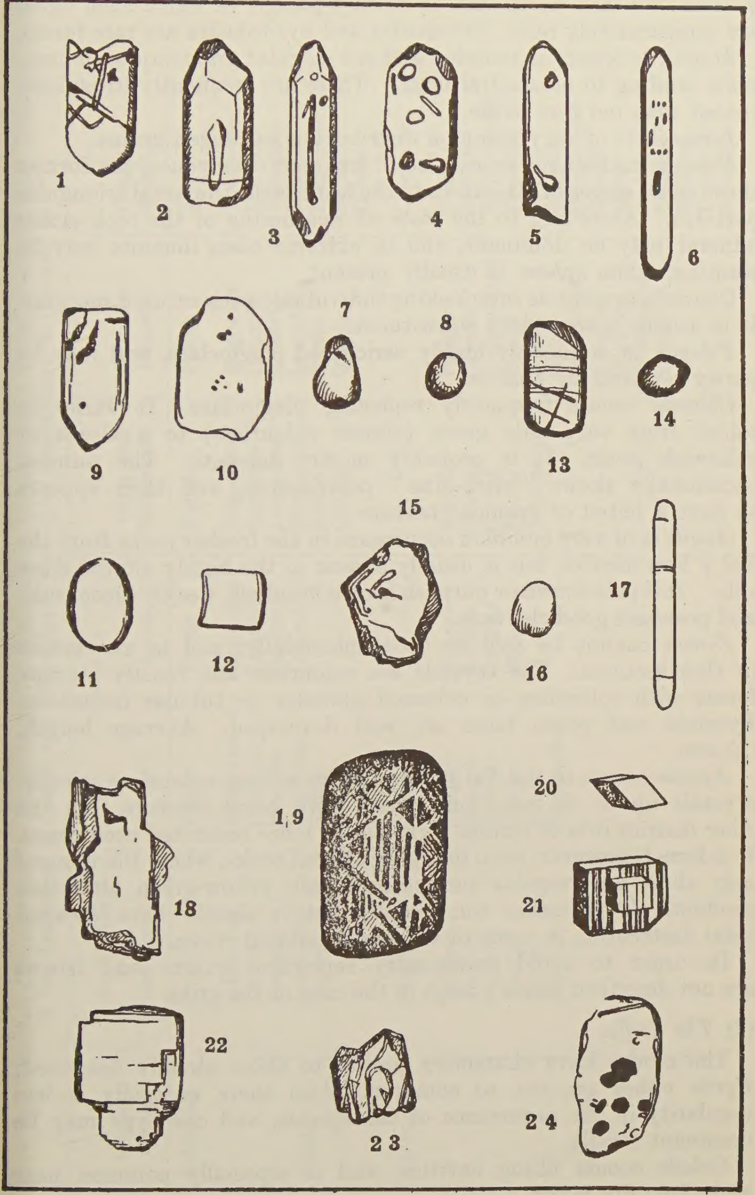

FIG. 1.—Minerals from Ordovician Rocks and Glacial Deposits of North-East Carnarvonshire.

quarter of a mile north-east of Wern-y-pandy, in which such cubes are comparatively rare. Octahedra and pyritohedra are rare forms.

Magnetite occurs as rounded and sub-angular grains up to ·5 mm., some tending to octahedral form. These are frequently irregularly coated with red iron oxide.

Limonite is of very common distribution as ragged grains.

Ilmenite and *leucoxene* are also of frequent occurrence, the former showing all stages of alteration to the latter with the usual triangular patterns. According to the state of weathering of the rock either mineral may be dominant, and in extreme cases ilmenite may be wanting, when *sphene* is usually present.

Quartz is present as interlocking individuals with sutured margins. It is usually a secondary constituent.

Felspar is commonly highly sericitized plagioclase, and may be partly replaced by *epidote.*

Chlorite occurs frequently replacing plagioclase. It varies in colour from very pale green (almost colourless) to a bluish or yellowish green. It is probably mostly delessite. The mineral occasionally shows " ultra-blue " polarization, and then appears to have a felted or granular texture.

Augite is of very common occurrence in the fresher rocks from the Tal y Fan district, but is usually absent in the highly altered Aber sills. It is pale brown or purplish brown in colour, weakly pleochroic, and possesses good cleavage.

Zircon cannot be said to occur plentifully, and is uncommon in thin sections. The crystals are colourless and mostly stumpy forms with colourless or coloured globular or tubular inclusions. Pyramid and prism faces are well developed. Average length, ·15 mm.

Apatite occurs in the Tal y Fan district as long colourless acicular crystals up to ·21 mm. long, some with basal fracture. In the Aber district it is of similar form but of more restricted occurrence. It is found, however, even in highly altered rocks, where the mineral may show an irregular surface and pale yellow-green alteration product. It is rather remarkable that it should have escaped total destruction in some of the highly altered rocks.

In order to avoid unnecessary repetition quartz and felspar are not described below except in the case of the grits.

(2) *The Tuffs.*

The oxides have characters similar to those already described. *Pyrite* cubes are not so common. Also there naturally is less regularity in the occurrence of the species, and one type may be dominant locally.

Calcite occurs filling cavities, and is especially common near and along dip faults.

Garnet occurs rarely as rounded or sub-angular grains with a hackly or fractured surface. They range in size from ·09 to ·25 mm.,

TABLE I.

TABLE TO SHOW THE GENERAL DISTRIBUTION OF CHARACTERISTIC MINERALS IN COMMON ROCK TYPES OF NORTH-EAST CARNARVONSHIRE.

N.B.—Leucoxene is classed with the oxides in view of its association with Ilmenite.

Mineral Group.	Basic Sills and "Greenstones"	Tuffs.	Lavas.	Grits and Sediments.	Glacial Deposits.	Coastal Sands.
Sulphides	Pyrite	Pyrite	Pyrite	Pyrite	Pyrite	Pyrite
Oxides	Magnetite Limonite Ilmenite Leucoxene Quartz	Magnetite Limonite Ilmenite Leucoxene Rutile Quartz	Magnetite Limonite Ilmenite Leucoxene	Magnetite Limonite Leucoxene Hematite Rutile Quartz	Magnetite Limonite Ilmenite Leucoxene Rutile Quartz	Magnetite Limonite Hematite Ilmenite Leucoxene Rutile Quartz
Carbonates	Calcite	Calcite				Calcite
Silicates	Felspar Sericite Chlorite Augite Zircon Epidote	Felspar Sericite Chlorite Garnet Zircon Tourmaline	Felspar Sericite Chlorite Zircon	Felspar Chlorite Garnet Zircon Tourmaline	Felspar Chlorite Hypersthene Augite Garnet Zircon Andalusite Kyanite Epidote Tourmaline Staurolite	Felspar Chlorite Hypersthene Enstatite Augite Diopside Hornblende Garnet Zircon Andalusite Kyanite Epidote Tourmaline Staurolite
Phosphates	Apatite	Apatite		Apatite	Apatite	Apatite

and some have a pale pink tint. They are normally isotropic, but a few have anisotropic inclusions.

Zircon is very common usually. Rounded colourless types are of most frequent occurrence, with rough surfaces and crowded with translucent globular and tubular inclusions. Some inclusions are opaque. The prismatic crystals are mostly stumpy with an average length of ·2 mm. Small well-formed crystals commonly ·1 mm. long occur also. Some crystals are of a pink or pale yellow tint. One colourless crystal had one pear-shaped and five globular inclusions, each of a definite pink colour.

The typical purple zircon is also rarely present as well-worn ovoid grains under ·2 mm. diameter. Purple zircons have been found in the Aber district and also in the tuffs of the Tal y Fan district, and are of fairly wide distribution.

Rutile is of very rare occurrence and has so far only been found in the Tal y Fan area. The grains are well-rounded and of dark yellow-brown colour with an average length of ·1 mm.

Apatite has been observed in tuffs from Tal y Fan. It is a rare constituent and occurs as broken fragments or prismatic grains up to ·8 mm. long terminated by basal fractures. Some rounded or almost spherical grains occur also. The mineral is colourless and the surface shows that considerable solution has occurred. It might perhaps be expected that apatites would have already disappeared from these rocks.

(3) *The Lavas.*

The residues obtained by crushing the rhyolitic lavas naturally yield very few minerals. In addition to iron ores, *magnetite*, *pyrite*, *ilmenite*, and *limonite*, *zircon* is the only interesting constituent. Rhyolites have been examined from Drosgl and Foel Lwyd to Cefn Llechen, south-west of Conway.

Zircon occurs as well-formed colourless prisms with fairly low pyramids. The form (100) is most strongly developed and (110) is nearly always present. Forms (101) and (331) have been noted, the latter being uncommon. The globular and elongated inclusions are colourless. The average length of the crystals is ·77 mm., with a width of ·18 mm. Some crystals show diagonally intersecting cracks.

Garnet has been recorded from similar rocks elsewhere,[1] but in this district must be of local and not general occurrence, as of the many residues examined none gave traces of its presence. It is extremely likely that much of the *chlorite* is pseudomorphous after garnet. Much *sericite* is usually present.

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[1] H. Williams, "The Geology of Snowdon (North Wales)," *Q.J.G.S.*, vol. lxxxiii, 1927, p. 390. The author states that almandine garnets are "plentiful" in similar rocks in the Sychnant Pass. See also same author, Geol. Mag., 1922, p. 187.

(4) *The Grits and other Sediments.*

Pyrite occurs usually as irregular secondary aggregates, separate grains in the crushed rock averaging half a millimetre. Crystal forms are rare. On Cae'r Mynydd, south of Aber, pyritized pisolitic grains occur.

Magnetite occurs fairly frequently as blue-black worn grains commonly ·2 mm. diameter, but may be ·3 mm. or more.

Limonite is frequent and occurs in compound grains with pyrite. It is especially common in disturbed tracts.

Leucoxene is present among the abundant opaque white material, but the triangular pattern of partially altered ilmenite has not yet been observed. A test for titanium confirmed the determination.

Rutile is an uncommon constituent. It is found as dark, red-brown, or yellowish worn grains, usually stumpy, measuring ·2 mm. long. It is not present in all the crushed grits examined. The surface of the grains is sometimes rough or pitted or coated with opaque matter.

Quartz occurs as sub-angular or rounded grains and is in excess of felspar.

Felspar may be sericitized or chloritized and may be rarely found with epidote.

Chlorite is a common constituent. It is usually of a bluish-green colour and may be platy or fibrous. It is very common in the schistose grits along dip faults.

Garnet is a rare constituent in the Tal y Fan region but is more common in the older sediments of the Aber district. The grains are isotropic, exhibit a hackly fracture, and are mostly colourless or weakly tinted and fairly free from inclusions. They are usually less than ·2 mm. diameter.

Zircon is a very common mineral throughout the grits, but its concentration may vary locally. It may make up more than 90 per cent of the translucent minerals of the heavy residue. It is mostly colourless, but pink and good purple zircons occur rarely throughout. Some pale yellow-tinted zircons may be found also, but zoning is a rare feature in zircons from the grits. The well-known typical purple zircon does not seem to have been definitely recorded from Ordovician rocks hitherto. In a recent paper on the distribution of purple zircons, Professor Boswell[1] published a table showing British formations from which purple zircons have already been obtained, their presence in the Ordovician System being queried. The present writer had proved the presence of purple zircons in grits of probable Arenig age from the Aber district in 1923, but publication was delayed to allow of more complete investigation, which was amply justified by their discovery in tuffs and grits of Llandeilo age from the Tal y Fan region. Thus they are probably of general occurrence throughout the whole Ordovician System. Boswell draws a distinction between purplish brown and good rose pink or purple zircons; both types occur in the Ordovician rocks examined. The purple zircon is of such a definite character that its occurrence is indicated by a separate column in the table of results.

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[1] P. G. H. Boswell, "On the Distribution of Purple Zircon in British Sedimentary Rocks," *Min. Mag.*, vol. xxi, 1927, p. 314.

The variety usually occurs in Arenig rocks as rounded or ovoid well-worn grains commonly ·2 mm. diameter. The intensity of the colouring varies. Their rounded character indicates that they have travelled from a considerable distance, and Scotland has been often suggested as a possible source of origin.[1] In the Llandeilo rocks the variety is of similar type, but brownish purple forms occur also. One rose pink crystal, however, exhibited perfect pyramid and prism faces, which suggests that this variety may possibly have a nearer source than that indicated above. Some of the pink zircons have inclusions which give a pale grey colour between crossed nicols.

Three other types of zircon occur in the grits of both ages.

(1) Well-formed prisms and pyramids, with dark or globular or tubular inclusions. The faces may be slightly worn at the edges or the terminations may be worn only, or the crystal faces may be entirely unworn. The crystals are commonly between ·2 and ·1 mm. in length. Some are slender and of ·03 mm. in width, whilst others are comparatively stumpy and measure ·1 mm. or more across. Some give undulose extinction. The crystals are usually colourless but may be pale yellow or pale grey. A few are tinted yellow at one end and shade off to colourless at the other. Rod-like inclusions occasionally occupy the whole length of the crystal.

This type is the most common.

(2) A less common ovoid variety averaging ·12 mm. diameter, sometimes with a pitted surface. The rounded crystals may reveal under high power both concentric and radial fracturing due no doubt to the constant rolling and buffeting during deposition. This variety is mostly colourless.

(3) A distinctly larger type, composed of rounded and fractured or prismatic grains commonly ·4 or ·5 mm. in length by ·2 mm. diameter. The surface may be rough and the crystals are colourless. The variety is not of such frequent occurrence as the two types described above.

Tourmaline occurs as a fairly common constituent in most grits as rounded or prismatic grains averaging ·3 mm. long by ·15 mm. broad. The mineral exhibits very strong pleochroism from a dull brown or reddish brown or pale pinkish brown to olive or bluish green, or from yellow or green to almost colourless. Rarely bluish grains occur, which may show blue and brown colour zoning. The grains frequently contain elongated and globular inclusions, sometimes opaque.

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[1] W. Mackie, "The Source of the Purple Zircons in the Sedimentary Rocks of Scotland," *Trans. Edin. Geol. Soc.*, vol. xi, 1923, pp. 200–13.

Apatite is a rare constituent. The grains are mostly well rounded, and average ·14 mm. in length, but a few prismatic grains occur up to ·3 mm. long terminated by basal fractures. The crystals may show a corroded surface.

Boswell[1] has described mineral assemblages from the zones of *Monograptus nilssoni* and *M. scanicus* on the Denbighshire Moors, and remarks that the minerals might have been derived from the Ordovician sediments to the south or west of the Moors. The above analyses show that this suggestion now becomes a probability. It is to be noted, however, that the zircons obtained from the Silurian graptolite zones were colourless and apatite was not recorded. The latter mineral is so rare in the Ordovician rocks that its absence in later sediments may be accounted for. Pink or purple zircons were not recorded by Boswell, and this is more worthy of note owing to the persistence of the species. It is possible that more extended and detailed work would reveal their presence in Silurian rocks in the surrounding district. The absence of both minerals might be explained by supposing them to have passed through more than one cycle of sedimentation. The same author records a similar suite but with greyish zircon from the zone of *M. leintwardinensis* south-west of Ruthin.[2]

(5) *The Glacial Deposits.*

The brief description of minerals from the Glacial deposits will serve also for the coastal and river sands since no appreciable difference has been observed in their characters. A very distinct relationship has been traced between the underlying geology and the Glacial and stream deposits at high elevations, especially in the more rugged country where the deposits are thin. Thus where ophitic dolerites predominate, augite, ilmenite, leucoxene, and chlorite form the bulk of the heavier constituents, whilst on the rhyolitic lavas zircon is conspicuous in the stream-beds. It appears that the bulk of the upland drift filling the broad valleys of north-east Carnarvonshire is of local origin, for it is only on the lower ground near the coast that the assemblages are found to contain minerals not obtained by crushing local Ordovician rocks.

Magnetite occurs in the drift as sub-angular blue-black grains, sometimes showing octahedral form. Many compound grains occur, altering to *Limonite.*

Ilmenite is a common constituent. Some grains are unaltered, whilst others show all variations of the triangular pattern

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[1] P. G. H. Boswell, "A Contribution to the Geology of the Eastern Part of the Denbighshire Moors," *Q.J.G.S.*, vol. lxxxii, 1926, pp. 563–73.

[2] P. G. H. Boswell, "The Salopian Rocks and Tectonics of the District South-West of Ruthin (Denbighshire)," *Q.J.G.S.*, vol. lxxxiii, 1927, p. 696.

TABLE II.

SELECTED RESULTS OF MINERAL ANALYSES OF 35 ROCK TYPES FROM NORTH-EAST CARNARVONSHIRE.

The presence of a mineral is indicated by its initial letter. Capitals and italics denote extreme abundance and rarity respectively. Quartz and Felspar are not shown, since they occur in all the rocks examined.

Rock.	Locality.	Calcite.	Pyrite.	Magnetite.	Limonite.	Hematite.	Ilmenite.	Leucoxene.	Rutile.	Chlorite.	Hypersthene.	Enstatite.	Augite.	Diopside.	Hornblende.	Garnet.	Zircon.	Purple Zircon.	Andalusite.	Kyanite.	Epidote.	Tourmaline.	Staurolite.	Apatite.
Diabase	¼ mile N.E. of Maes y Gaer . .	—	P	—	l	—	—	—	—	c	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,,	¼ mile N.E. of Wern-y-pandy . .	—	p	—	l	—	—	l	—	c	—	—	—	—	—	—	—	—	—	—	—	—	—	*a*
,,	North slopes of Meuryn Isaf .	—	—	m	—	—	i	l	—	c	—	—	—	—	—	—	z	—	—	—	*e*	—	—	*a*
,,	N.W. of Bont-newydd	—	p	*m*	l	—	—	—	—	c	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,,	Old Quarry, Wern-y-pandy . .	c	P	—	l	—	—	—	—	c	—	—	—	—	—	—	*z*	—	—	—	—	—	—	—
"Green-stone"	South of Maes y Gaer	—	p	m	l	—	—	—	—	c	—	—	—	—	—	—	—	—	—	—	—	—	—	*a*
,,	¼ mile S.E. of Maes y Gaer . .	—	p	m	l	—	—	l	—	c	—	—	—	—	—	—	—	—	—	—	e	—	—	*a*
Dolerite	Craig Celynin . .	—	*p*	m	l	—	i	l	—	c	—	—	A	—	—	—	—	—	—	—	—	—	—	—
,,	Sill S. of Slate Quarry Tal y Fan .	—	—	m	—	—	i	l	—	c	—	—	a	—	—	—	*z*	—	—	—	—	—	—	*a*
,,	East of Cae Iol .	—	—	m	—	—	i	l	—	c	—	—	a	—	—	—	*z*	—	—	—	—	—	—	—
,,	South of Craig Celynin . .	—	—	m	—	—	i	l	—	c	—	—	a	—	—	—	—	—	—	—	—	—	—	—
,,	S.E. of Cerrig y Ddinas . .	—	—	m	—	—	i	l	—	c	—	—	a	—	—	—	—	—	—	—	—	—	—	—
,,	¼ mile west of Hafotty . .	c	—	m	—	—	i	l	—	c	—	—	a	—	—	—	*z*	—	—	—	—	—	—	—
Tuff .	East of Tal y Fan .	—	p	m	l	—	—	—	—	c	—	—	—	—	—	—	z	—	—	—	—	t	—	—
,, .	North of Tal y Fan .	—	p	m	l	—	i	l	—	c	—	—	—	—	—	—	z	*z*	—	—	—	t	—	*a*

,, .	S.E. slopes of Tal y Fan . . .	—	—	*m*	—	—	i	l	—	c	—	—	a	—	—	—	—	—	—	—	—	—	—	*a*
,, .	Bronheulog, South of Conway . .	—	—	m	l	—	i	l	—	c	—	—	—	—	—	—	z	—	—	—	—	t	—	*a*
,, .	East of Nant . .	—	p	m	l	—	—	—	—	C	—	—	—	—	—	*g*	z	*z*	—	—	—	t	—	*a*
Rhyolitic Lava .	Quarries by Tyddyn-grasod . .	—	*p*	m	l	—	—	—	—	—	—	—	—	—	—	—	z	—	—	—	—	—	—	—
,,	N.W. of Bronheulog	—	p	—	l	—	—	—	—	—	—	—	—	—	—	—	z	—	—	—	—	—	—	—
,,	Cefn Maen Amor .	—	p	*m*	l	—	—	—	—	—	—	—	—	—	—	—	z	—	—	—	—	—	—	—
Grit .	¼ mile East of Llwyn Penddu .	—	p	m	l	—	—	—	—	c	—	—	—	—	—	—	z	z	—	—	—	—	—	—
,, .	Tan-y-graig . .	—	p	m	l	—	—	—	*r*	c	—	—	—	—	—	—	z	*z*	—	—	—	—	—	—
,, .	North of Bronlledraeth . .	—	p	m	l	h	—	l	*r*	—	—	—	—	—	—	—	z	*z*	—	—	—	t	—	—
,, .	East of Cefn Maen Amor . . .	—	p	m	l	—	—	l	—	—	—	—	—	—	—	—	z	z	—	—	—	t	—	—
,, .	North of Ffriddlys .	—	p	m	l	—	—	—	*r*	c	—	—	—	—	—	—	z	*z*	—	—	—	t	—	—
,, .	Cefn Llechen . .	—	—	—	l	—	—	—	—	—	—	—	—	—	—	—	z	*z*	—	—	—	—	—	*a*
,, .	South of Cefn Llechen	—	—	m	—	—	—	l	r	c	—	—	—	—	—	*g*	z	—	—	—	—	t	—	—
,, .	East of Tyddyn-grasod . .	—	p	m	l	—	—	—	—	c	—	—	—	—	—	—	z	—	—	—	—	t	—	*a*
Coast Drift	West of Penmaenbach	—	*p*	m	l	—	i	l	*r*	c	*h*	—	a	—	*h*	g	z	*z*	*a*	*k*	*e*	t	*s*	*a*
Mountain Drift .	Craig Celynin . .	—	—	m	l	—	i	l	—	c	—	—	a	—	—	—	*z*	—	—	—	—	*t*	—	—
Shore Sand .	East of Penmaenmawr	—	*p*	m	l	h	i	l	*r*	c	*h*	—	a	—	h	g	z	—	a	*k*	*e*	t	*s*	a
,, .	North of Conway Mountain . .	*c*	p	m	l	*h*	i	l	*r*	c	—	—	a	—	—	g	z	—	a	—	*e*	t	s	*a*
River Sand .	West of Conway Estuary . .	*c*	p	m	l	—	i	l	*r*	c	—	—	a	—	—	g	z	—	*a*	—	*e*	t	*s*	*a*
Blown Sand .	East of Conway Estuary . .	c	p	m	l	h	i	l	*r*	c	h	*e*	a	*d*	h	g	z	*z*	a	—	*e*	t	*s*	*a*

characteristic of the change to *leucoxene.* A good example is here figured. Average size, ·5 mm.

Rutile is a rare constituent which is found as ovoid or prismatic reddish or yellowish brown grains, commonly weakly pleochroic and under ·2 mm. in length.

Chlorite occurs as well rounded green grains of various hues and sizes.

Hypersthene is a rare mineral in the drift and is confined to the coast belt in the vicinity of Penmaenmawr. It is usually found as broken prismatic grains exhibiting strong pink to green pleochroism. Some fragments have many minute inclusions (schiller). Average length, ·26 mm.

Augite is very common, and occurs as elongated pale brown fragments, mostly sub-angular, and ranging in length up to ·5 mm. Rounded grains are rare. Cleavage is sometimes distinct and pleochroism varies from brown to pinkish or yellowish brown.

Garnet may be pale pink or colourless, and usually shows a hackly fracture. Sometimes numerous globular or few acicular inclusions are present which give a grey colour between crossed nicols. The well rounded variety suggests transport from a distance, whilst the angular type may be local. The grains have an average diameter of ·25 mm.

Zircon is fairly common as rounded and prismatic crystals of all types, with or without globular and acicular inclusions. A few are perfectly formed and possibly local. Common sizes range between ·15 and ·2 mm. Purple zircons are also rarely present.

Andalusite occurs in the coastal drift as sub-angular clear grains or with numerous opaque or pale yellow inclusions, and showing strong pink to colourless pleochroism. The inclusions may make up 50 per cent of the mineral and the grains may reach ·5 mm. in length.

Kyanite is found rarely in the coastal drift as the usual type of cleavage grain measuring up to ·24 mm. in length and bounded by (100) and with good (010) and traces of (001) cleavages.

Epidote occurs as rounded yellowish green grains up to ·25 mm. diameter.

Tourmaline is common as variously coloured pleochroic prismatic or basal grains measuring up to ·5 mm. in length. Some well rounded grains averaging ·3 mm. are also fairly common.

Staurolite is present in the coastal drift as either clear sub-angular pale yellow grains, or crowded with globular and elongated coloured isotropic or opaque inclusions. The grains average ·2 mm. diameter.

Apatite is of fairly wide distribution and occurs mostly as well rounded or partially rounded prismatic grains up to ·3 mm. long, of a type found in the grit and tuffs.

In the coastal sands have been identified in addition: *enstatite, diopside, hornblende,* and *calcite.*

The minerals found in the drift which are foreign to the locality and which have been definitely derived from sources other than the Ordovician rocks are andalusite, staurolite, and kyanite. Some of the rounded garnets, purple zircons, and apatites may probably be added. It is significant that the first three are of metamorphic origin. They have been noted in a red clay exposed in the low cliffs west of Penmaenbach, which resembles that described from eastern Anglesey by Dr. Greenly,[1] in which case it is equivalent to the "Upper Boulder Clay" of Anglesey. It is probable that the kyanite and staurolite were derived from the Triassic rocks of the sea-floor to the north, a large part of which is made up of rocks of this system,[2] and the former mineral is not known to occur in Anglesey except possibly in the drift. Double[3] records kyanite and staurolite in Triassic pebbles from Anglesey considered by Dr. Greenly to have been derived from the sea-floor.

In conclusion, I wish to record my indebtedness to Mr. G. M. Davies for laboratory facilities and much helpful advice given throughout the progress of this research in the Geological Laboratory at Birkbeck College, University of London, during the last five years.

EXPLANATION OF FIG. 1.

No.
1. Yellow Zircon. Grit, Cefn Llechen. × 120.
2. Zircon. Lava, Cefn Maen Amor. × 120.
3. ,, Grit, South of Bont Newydd, Aber. × 70.
4. ,, Tuff, Foel Lwyd. × 120.
5. ,, Grit, North side of Tal y Fan. × 100.
6. ,, Grit, East of Maen Penddu. × 100.
7. Purple Zircon. Tuff, Tal y Fan. × 70.
8. Zircon. Grit, Tal y Fan. × 100.
9. Tourmaline. Grit, South of Cae-defeitty. × 100.
10. ,, Grit, Cefn Llechen. × 120.
11. ,, Grit, Tal y Fan. × 70.
12. ,, Tuff, Tal y Fan. × 70.
13. Rutile. Grit, West of Craig Celynin. × 120.
14. ,, Grit, Cefn Llechen. × 70.
15. Garnet. Grit, West of Foel Dduarth. × 70.
16. Apatite. Tuff, Tal y fan. × 70.
17. ,, Dolerite, North-east of Pen-y-ffrîdd. × 70.
18. Augite. Dolerite, Craig Celynin. × 100.
19. Ilmenite and Leucoxene. Coast Drift, East of Penmaenmawr. × 100.
20. Rhombohedral Carbonate. Fault-breccia, Pen-yr-allt. × 70.
21. Pyrite. Sill in mine adit, East of Maes y Gaer. × 70.
22. Kyanite. Coast Drift, West of Penmaenbach. × 70.
23. Staurolite. Coast Drift, West of Penmaenbach. × 40.
24. Andalusite. Coast Drift, West of Penmaenbach. × 40.

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[1] "Geology of Anglesey," *Mem. Geol. Surv.*, vol. ii, 1919, p. 704–5.

[2] See map in above *Memoir*, vol. ii, p. 778. Dr. Greenly has also suggested this possibility in the case of kyanite in a personal communication.

[3] I. S. Double, "The Petrology of Triassic Boulders from the Boulder Clay of Anglesey," *Proc. Lpl. Geol. Soc.*, vol. xv, pt. i, 1928, pp. 63–8.

On the Structural Relationships and Genesis of the Pyritic Ore-bodies of Huelva.[1]

By G. Vibert Douglas.[2]

THE Province of Huelva, famed for its mines from the times of the Ancients, lies in the south-western portion of Spain, in the upland between the basins of the Guadalquivir and Guadiana. To the north are the serrated ridges of the Sierra Morena and to the south the fertile plains of Huelva and Sevilla. This upland, now in a mature stage of erosion, forms the old coastal plain. It is composed of Palaeozoic rocks, chiefly Carboniferous, which lie unconformably on the pre-Cambrian gneisses and schists of the Sierra Morena. Miocene limestone and Pleistocene Drift in places obscure the Palaeozoic rocks. The Carboniferous rocks are principally slates and grits, the former being by far the more abundant. In what is usually regarded as Hercynian times and following great tectonic movements, the Carboniferous rocks were invaded by granites, porphyries, diorites, porphyrites, and diabase. The mineralization was associated with these intrusives and principally with the porphyries. Finally the area was reduced to a peneplain by erosion.

With this brief, general description of the area we can now pass to the ore-bodies.

The ore-bodies may be grouped into the following classes :—(*a*) Massive sulphides with slate walls ; (*b*) Contact bodies between porphyry and slate ; (*c*) Stockwork and disseminated sulphides entirely in porphyry ; (*d*) Veins carrying sulphides (of minor importance).

The present land surface, being a chance surface of erosion, is either above the upper limits of mineralization, or truncates the masses or their roots. Therefore the classification of the first three types represents various horizons in one great scheme, rather than isolated types of occurrence. Thus an idealized section would show a stockwork porphyry passing upwards into massive sulphides at the contact and above this zone, entirely in slate, lenticular bodies of sulphides. The outermost manifestations of mineralization are veinlets of quartz which may carry sulphides.

The sequence of events from the time when the slates were formed is as follows :—

The forces which were operative on the area prior to the intrusion of the igneous rocks must have been very uniform in the direction in which they were applied, because the strike and dip of the slaty cleavage developed in the argillaceous rocks is extraordinarily uniform. The average value of the strike is 95° true and the dip of the cleavage planes is 60°–80° north. It should be noted that these values refer to the cleavage of the slate as distinct from the bedding. The bedding, often parallel to the cleavage, is frequently seen crossing it (Fig. 1). From various sections which the writer has seen he is convinced that the bedded argillaceous rocks were first crumpled into anticlines and synclines and that finally, as the pressure continued, the folds were closed and a cleavage was developed. The cleavage direction was controlled by the tectonic forces and superimposed on the folded beds. The intrusion of the igneous rocks then followed, and their general courses were determined by the lines of least resistance offered by the slaty cleavage.

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[1] Published with the permission of the Chairman of the Rio Tinto Co., Ltd. This paper was delivered to Section C of the British Association for the Advancement of Science, Glasgow, September, 1928.

[2] Chief Geologist, Rio Tinto Co., Ltd.

As has been stated, most of the ore-bodies are associated with the porphyries and hence in the following context where intrusive or igneous rocks are mentioned, porphyry shall be understood, unless otherwise noted.

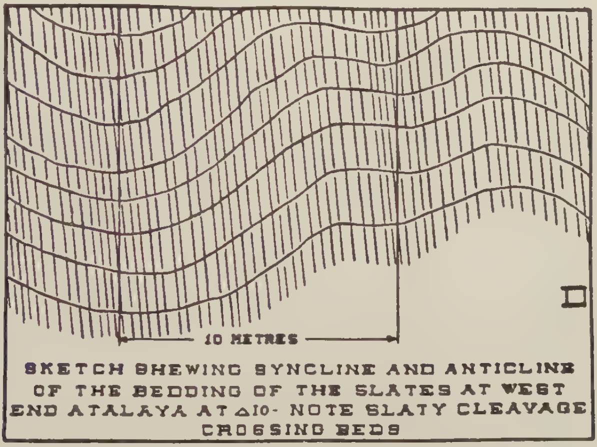
10 METRES
SKETCH SHEWING SYNCLINE AND ANTICLINE
OF THE BEDDING OF THE SLATES AT WEST
END ATALAYA AT △10- NOTE SLATY CLEAVAGE
CROSSING BEDS

Fig. 1.—Folding in Slates at W. end of Atalaya.

The porphyries were intruded as either dykes or sills. By the former is meant an igneous intrusive rock in which both flanks dip away from the central part of the body. By a sill is meant an igneous body which is injected along the slaty cleavage and has both of its walls dipping in the same direction.

The predominant porphyry intrusions in the Province of Huelva are sills, but dykes are also to be found. It will be seen that it is possible to have a dyke as an auxiliary feature to a sill. An example of this is the Salomon dyke at Rio Tinto, or the Mimbrera Hill north of the town of Zalamea. The neck between the dyke and the sill at Rio Tinto is overlain by slates, but at Zalamea it is denuded and the porphyry-slate contact would make, on a ground plan, an outline resembling a peninsula. These statements will be made clearer by referring to the idealized section and plan of Atalaya (Fig. 2). It is obvious that if the porphyry be injected as a dyke, the southern flank will cross the slaty cleavage, which is dipping north. Furthermore there will be greater resistance to intrusion where the porphyry transgresses the slaty cleavage than where the intrusive body slides up along the cleavage planes. The effects are two-fold: where the slate offers resistance to a porphyry dyke, the slate suffers greater brecciation and comminution than where the injection is along the cleavage. Secondly, the porphyry is subjected also to greater strains and hence suffers brecciation. Where it has been possible to study these injectional effects in the porphyry it is seen that there are two distinct types: (*a*) a shear, (*b*) a coarse brecciation. Where the coarse brecciation exists there is little shearing and vice-versa.

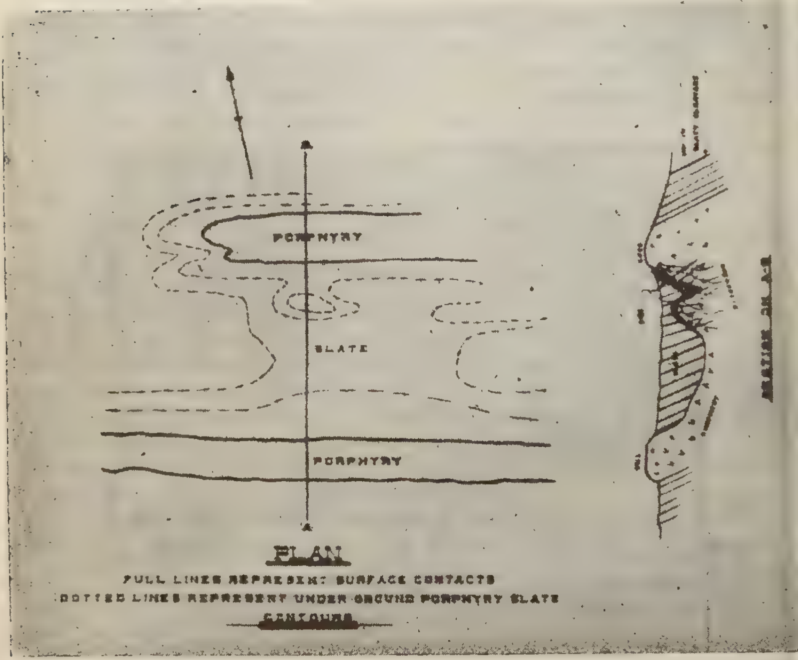
A
PORPHYRY
SLATE
PORPHYRY
A
PLAN
FULL LINES REPRESENT SURFACE CONTACTS
DOTTED LINES REPRESENT UNDER GROUND PORPHYRY SLATE CONTOURS
SECTION ON A-A

Fig. 2.—Atalaya, Idealized Plan and Section.

The shearing planes, although irregular, have approximately the same strike and dip as the cleavage of the slates and are best developed near the walls of the porphyry sills or on the north side of the dykes. These facts suggest that the shearing is an injectional effect produced by movement of a cooling viscous mass. The coarse brecciation, on the other hand, has the appearance of torsional shattering in a solid.

Daubrée's experiments on a glass plate[1] produced a pattern which closely resembles this brecciation. It is thought that this shattering was a later effect than the shearing and that where the porphyry was sheared, the torsional strains were taken up along the shear planes, but where the porphyry had crystallized normally, the result was to produce this brecciation.

The contact ore-bodies in the province which have been bottomed have been found to rest on brecciated porphyry. The cracks between the porphyry blocks are now filled with sulphides and gangue minerals and this ensemble is called a stockwork porphyry (Figs. 3 and 4).

The slates which form the roofs of the ore-bodies have been affected by the intrusion of the porphyry and by the alteration due to the mineralizing solutions and vapours. Where the porphyry has enclosed large keel-shaped masses of slate or has cut across the slaty cleavage, the slate has been intensely altered. Where the porphyry has slid up along the slaty cleavage there has been little alteration, because the slate is almost impermeable to solutions in a direction normal to a cleavage plane. The physical result of this alteration is a general softening of the slates with sericitization.

The writer's picture of the mineralizing process is as follows:—The parent magma in depth separated into two parts: A silicate magma which was injected as either a dyke or a sill, and a sulphide solution or colloid which tended to remain behind in the parent couche. After the consolidation of the outer zone of the silicate magma with the attendant auto-shearing and auto-brecciation, the shrinkage of the porphyry, due to its cooling, brought pressure to bear on the couche and as a consequence the sulphide solutions were forced to rise. These tenuous and highly mobile hydrothermal solutions (or colloids) found an egress through the channelways afforded by the stockwork crevices and to a lesser extent through the shearing planes of the porphyry. They continued to rise until they reached the zone of comminuted contact rocks and there, under favourable conditions of temperature and pressure, the sulphides were deposited, while the hot water, bearing away the replaced country rock, passed on to the surface finally to be lost in the sea. As an example of the work of cold underground water, Schardt[2] found that the underground drainage from one fault in the Simplon Tunnel carried away ten thousand cubic metres of calcium sulphate each year. If cold waters are capable of doing this work, it should not be difficult to think of water, at higher temperatures and pressures, acting for a long time, as the carrier of the ore minerals and the remover of the comminuted rock. At

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[1] *Études synthétiques de Géologie Experimentale*, Paris, 1879.

[2] L. W. Collet, *The Structure of the Alps*. London, Arnold, 1927.

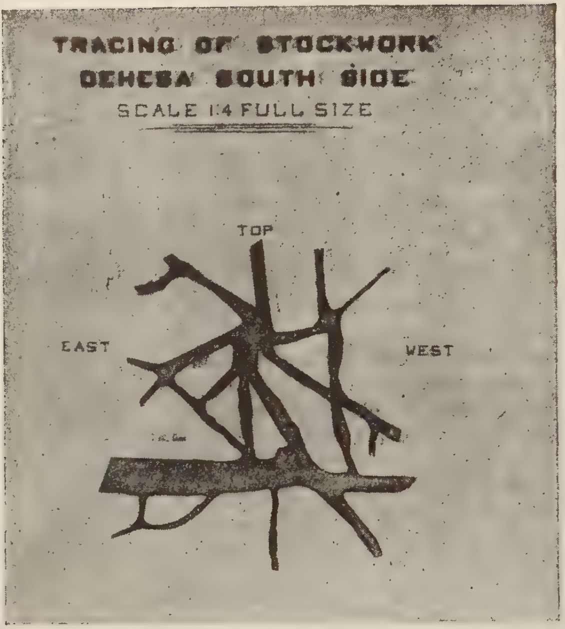

FIG. 3.—San Dionisio, Stockwork.

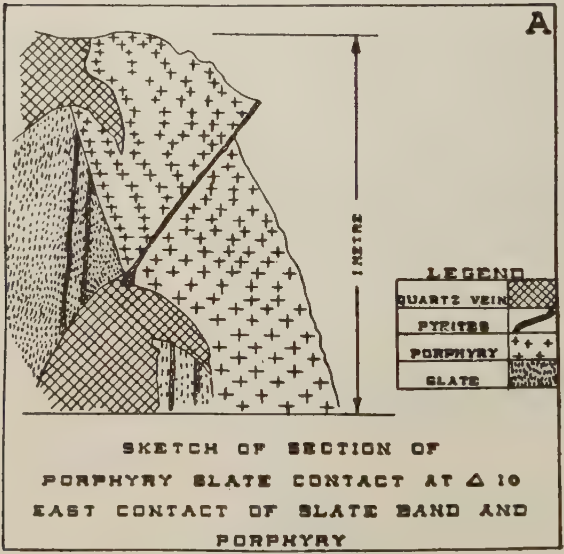

FIG. 4.—Porphyry-Slate Contact.

the present time aluminium sulphate can be detected in the waters from some of the adits at Rio Tinto.[1]

This outline of the mineralizing processes demands the following structural conditions: (*a*) Permeability for solutions in the porphyry; i.e., a stockwork. (*b*) Roof conditions favourable for deposition; i.e., slates end-on to the porphyry contact.

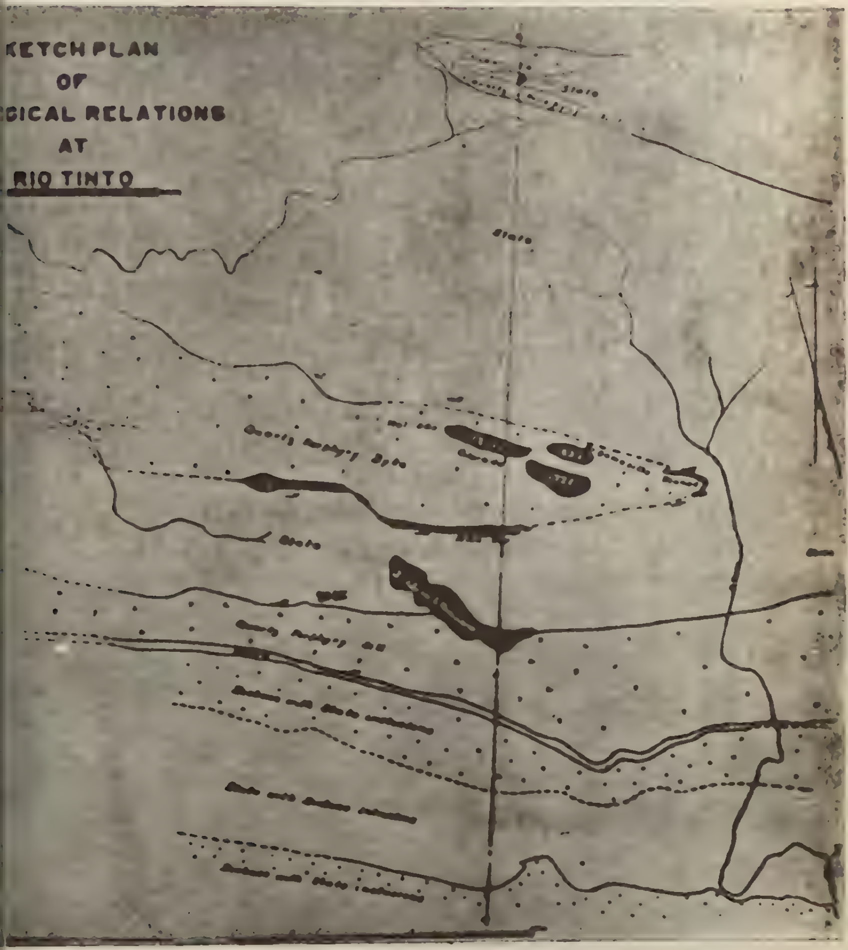

Fig. 5.—Sketch-plan of Rio Tinto area.

With these two conditions and with what has been explained already it will be seen that the favourable structural field conditions are: (*a*) Roof pendants of slate in porphyry. (*b*) A slate roof in which the dip of the slaty cleavage is towards the porphyry.

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[1] Personal communication from B. Legg, late analyst Rio Tinto Co., Ltd.

Examples of (*a*) are to be seen in the Chaparrita (Figs. 5 and 6),

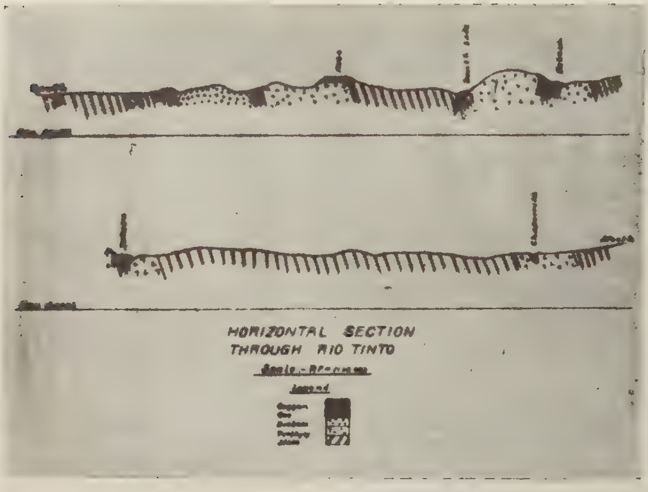

FIG. 6.—Horizontal section, Rio Tinto

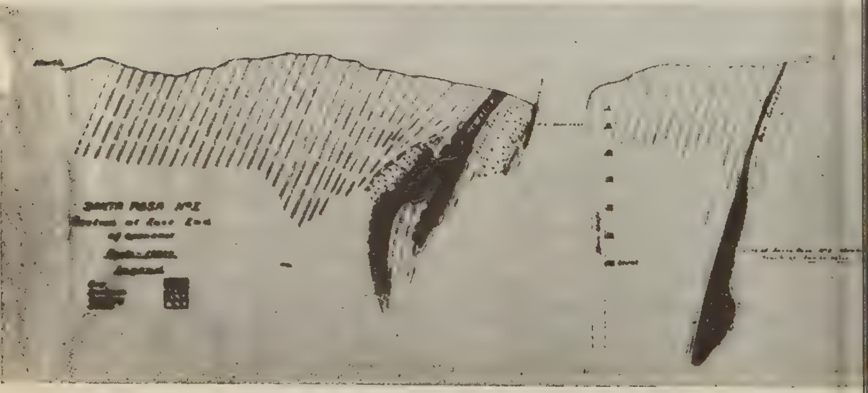

FIG. 7.—Section of Santa Rosa Mine.

the Peña mine, the North Lode group at Rio Tinto (Figs. 5 and 6), the Santa Rosa mine (Fig. 7), and many others.

Examples of (*b*) are: San Dionisio (Fig. 8), the South Lode at Rio Tinto, and La Zarza (Fig. 9). As can be seen by an inspection of Fig. 8, classes (*a*) and (*b*) really merge one into the other, depending on the depth at which the section is considered.

Above this zone of mineralization there are lenticular bodies in the slate, such as the Valle Lode of Rio Tinto (Fig. 10), the San Cornelio or southern lode at Santa Rosa (Fig. 7), besides others. These lodes represent the mineralization along certain cleavage planes and the slates are both bent and crosscut to make room for the ore. This indicates considerable pressure either as vapour pressure before, or as liquid pressure during, the period of mineralization and replacement.

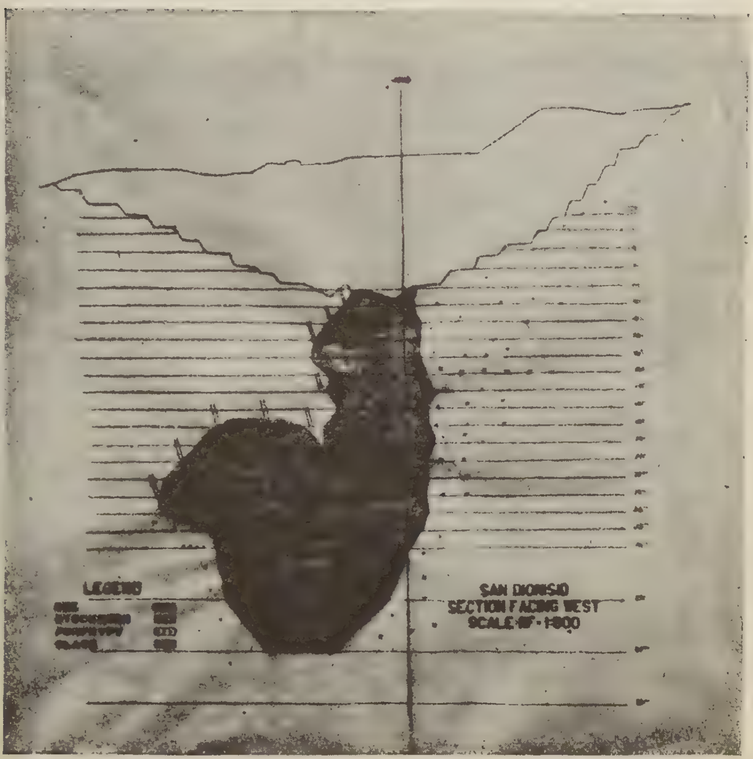

Fig. 8.—Section of San Dionisio Ore-body.

Below the zone of the contact ore-bodies there are the stockwork porphyry masses. At Rio Tinto in the North Lode group the stockworks carry both pyrites and chalcopyrite, and they are of such a tenour as to be considered profitable ore. These stockworks have been explored to considerable depths and have definitely been shown to carry sulphides to over 100 metres below the lowest portion of the massive ore. At this depth there is no indication that the stockwork is decreasing.

Where the stockwork veinlets are closely spaced, it is often possible to trace the gradual passage of a strong stockwork porphyry into a massive sulphide ore-body. The walls of the veinlets comprising the stockworks have been pyritized and it is obvious that if two veinlets are close enough together the pyritization of the walls of the one may merge with the pyritization of the walls of the other. When this process is continued there is very little rock material left and the result is a pyritic ore-body. Examples of this particular type of stockwork are to be seen in the Planes and Lago masses at Rio Tinto (Fig. 11). The writer's conception of the zone still lower than the known stockworks is that of a porphyry with blebs and disseminations of sulphides. Although areas in this Province where this deeper zone is exposed have not yet been examined, the view advanced here is in accord with the experimental results obtained by Stansfield.[1]

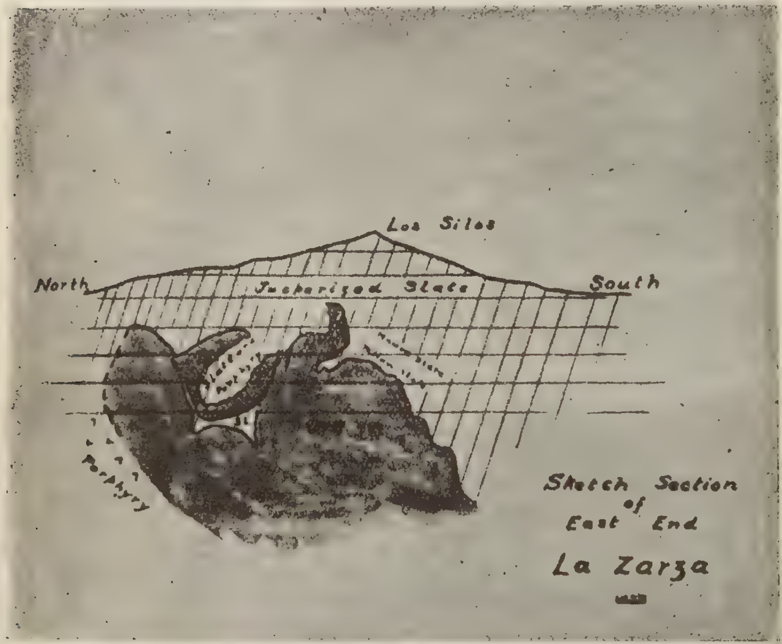

FIG. 9.—Section of La Zarza Ore-body.

Rastall's[2] generalization regarding the separation (crystallization)

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[1] J. Stansfield, *Assimilation and Petrogenesis: Separation of Ores from Magmas*, pp. 141–83, Valley Pub. Co., Urbana Ill.

[2] R. H. Rastall, *Physico-Chemical Geology*, London, Arnold, 1927, p. 200.

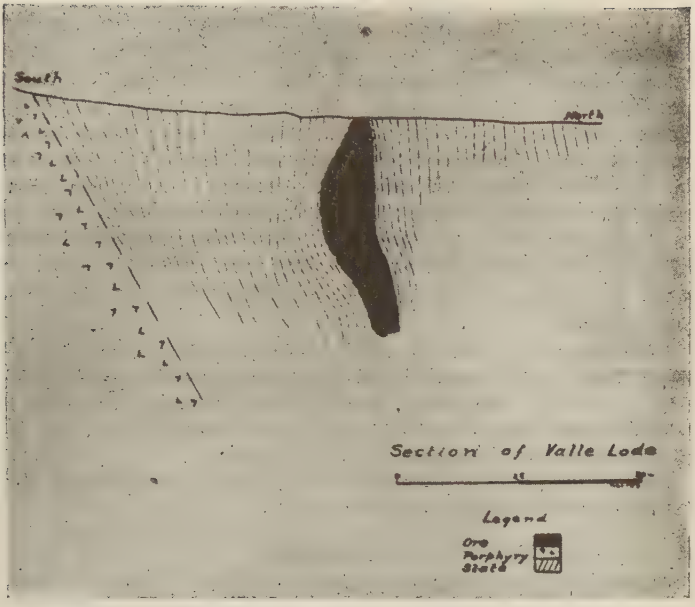

FIG. 10.—Section of Valle Lode.

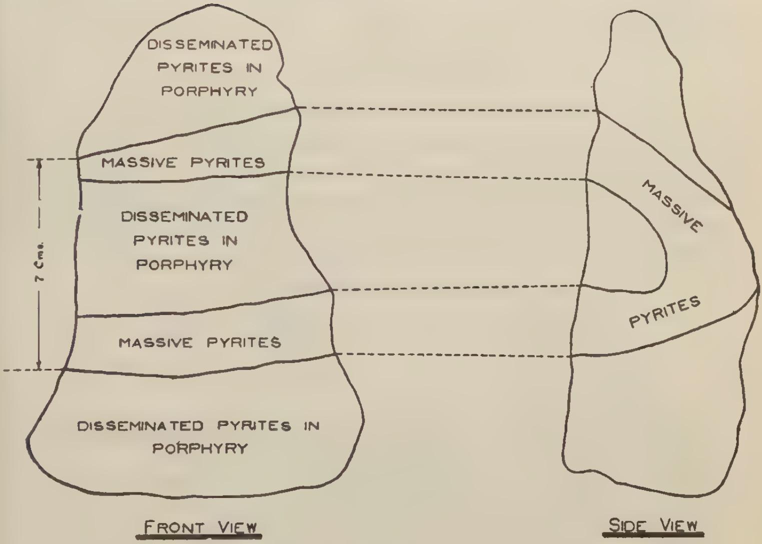
DISSEMINATED PYRITES IN PORPHYRY
MASSIVE PYRITES
DISSEMINATED PYRITES IN PORPHYRY
MASSIVE PYRITES
DISSEMINATED PYRITES IN PORPHYRY
7 Cms.
MASSIVE
PYRITES
FRONT VIEW
SIDE VIEW

FIG. 11.—Stockwork at Rio Tinto.

of the ores from acid and basic magmas also finds confirmation in the experiments carried out by Stansfield. The acid rocks are usually conceded to have had a higher water content than the basic rocks. If this be the case, then in acid magmas there are more bubbles and hence greater facilities for flotation of the sulphides. Under pressure, the rise of the bubbles and the attached sulphides would be accelerated, with the result that the H_2O molecules would be forced to enter the zone of fracture. The conditions of temperature and pressure existing in this zone would be such as to allow the steam to condense. The writer believes that the sulphides then went into solution and were carried upward to the zones of intense brecciation where replacement and precipitation took place.

The basic rocks, on the other hand, having a lower content of water would not have sufficient bubbles of steam included in the magma to effect the flotation of their sulphides. Therefore upon consolidation these sulphides are found towards the base of the igneous bodies, e.g. Sudbury.

These remarks, in so far as they apply to the Province of Huelva, can be summarized in columnar form.

SURFACE.

Slate roof and sulphide bodies.

Contact zone and sulphide bodies.

Stockwork porphyry zone, often carrying sufficient values to be worth mining.

Zone of disseminations and blebs.

(= Stansfield's experimental zone.)

Replacement versus Magmatic Injection.

There has been a considerable literature published in recent years regarding the origin of the pyritic ore-bodies of Huelva. Various geologists hold that the masses are magmatic injections, similar to the Norwegian deposits. It may be of interest to have these writers arranged according to their views :—

For Replacement by hydrothermal solutions.

Gonzalo y Tarin[1]
J. W. Gregory[2]
A. M. Finlayson[3]
H. F. Collins[4]
A. M. Bateman[5]
L. C. Graton[6]
G. Vibert Douglas[7]

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[1] Gonzalo y Tarin, *Bol. Comp. Mapa Geol. España*, Madrid, 1886–8. Tarin favours open space filling by sulphides deposited from solution.

[2] Gregory, *Elements of Economic Geology*, Methuen and Co., Ltd.

[3] Finlayson, *Econ. Geol.*, vol. v, 1910.

[4] H. F. Collins, *Trans. Inst. Min. and Met.*, 1921–2.

[5] Bateman, *Econ. Geol.*, vol. xxii, 1927.

[6] Graton, Personal communication to the writer.

[7] G. Vibert Douglas, *Nature*, 15th Oct., 1927.

For Magmatic Injections.

J. H. L. Vogt[1]
P. Krusch[2]
R. H. Rastall[3]
C. G. Cullis[4]
A. B. Edge[5]
J. Hereza[6]

During the autumn of 1928 the writer visited Norway for the express purpose of studying the typical Norwegian Pyritic Deposits.

Professor Vogt advised a study of Sulitelma, as being a typical deposit.

Vogt's views may be summarized as follows :—

(*a*) Gabbro phacoliths and sheets invading the country rocks (schists).

(*b*) Differentiation in depth of the sulphides in the gabbro magma.

(*c*) Injection of the sulphides as a sulphide magma into schists, usually below but sometimes above the gabbro.

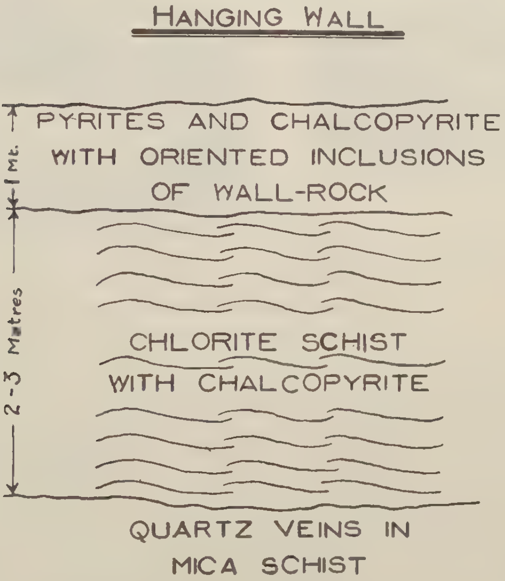
HANGING WALL
PYRITES AND CHALCOPYRITE WITH ORIENTED INCLUSIONS OF WALL-ROCK
1 Mt.
CHLORITE SCHIST WITH CHALCOPYRITE
2-3 Metres
QUARTZ VEINS IN MICA SCHIST

FIG. 12.—Sketch Section of Face of Ore in Gekin Mine, Sulitelma.

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[1] Vogt, *Ore Deposits*, Beyschlag, Vogt, Krusch. Macmillan and Co., Ltd.

[2] Krusch, *Die Untersuchung und Bewertung von Erzlagerstätten*, Stuttgart, 1920.

[3] Rastall, *The Geology of the Metalliferous Deposits*, Cambridge, 1923, p. 247; *Physico-Chemical Geology*, Arnold and Co., 1927.

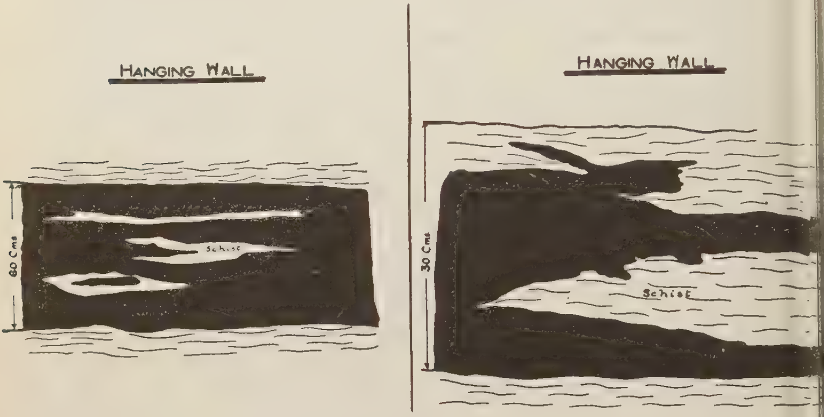
[4] C. G. Cullis. Unpublished letter read during discussion on paper delivered by G. V. Douglas to Sect. C, Brit. Assn., 12–9–28.

[5] Edge, Personal communication to the writer.

[6] Hereza, Guide Book, A–3, xiv, Int. Geol. Cong., Madrid, 1926.

(*d*) The ore shows large crystals of iron pyrites surrounded by finer grained sulphides. This ore can be likened to porphyritic rock with the iron pyrites forming phenocrysts in a matrix of sulphides.

The field evidence, regarding the origin of the sulphides, noted during the visit to Sulitelma did not in the writer's opinion confirm Professor Vogt's views. The ore occurs as large lenticular sheets in schist, and the general cross section is as shown in the accompanying sketch (Fig. 12).



SKETCHES SHEWING SCHIST REMNANTS IN ORE
GEKIN MINE SULITELMA

FIG. 13.

It is not the purpose of this paper to describe this area but the following summary is given :—

(*a*) Numerous inclusions of schist in the ore. The schist remnants have the same orientation as the hanging and foot-walls. This fact favours a gentle replacement more than a magmatic stoping action (Fig. 13).

(*b*) In the walls there are lenticular pods of ore up to two or three metres in length, detached from the massive ore.

(*c*) Below the massive ore the cupreous chloritic schists suggest hydrothermal solutions.

(*d*) Quartz veins traverse the ore and schists ; calcite and zeolites are also found associated with the ore.

(*e*) The massive ore has not got chilled margins which would be expected if the ore had been intruded as a magma.

(*f*) Some of the masses have been bottomed in depth in schist. If these sulphides had been magmas, it is difficult to conceive of them as passing through the laminæ of a schist. Dykes and volcanic pipes are not bottomed in a few hundred metres but the hydrothermal veins which are often associated with these bodies are sometimes traced to their source in the parent body (e.g. the diabase sheet at Cobalt, Ontario).

The writer believes that Sulitelma and Orkla, being the two mines which he visited, can both be explained satisfactorily by replacement by hydrothermal solutions.

To return to the Huelva field, it is also his belief that these deposits are hydrothermal replacements of porphyry and slate. Bateman, in his recent paper gives a mass of evidence in favour of replacement. Further evidence may be stated as follows :—

(*a*) The stockwork veinlets vary in width from a metre to less than a millimetre in a single specimen. The composition of the vein matter in these extremes is the same. Therefore the " Carrier " that deposited the ore in the one did so in the other at the same time. It is inconceivable that a magma with only 20 per cent H_2O or less, could traverse these veinlets for considerable distances and stay liquid; whereas in the Valley of Ten Thousand Smokes, in the Azores, in Java and at a host of different localities, sulphides and other minerals are now being deposited by hydrothermal solutions which have traversed cracks in the earth's crust.

(*b*) There are undoubted horses of both slate and porphyry in the ore—these have been frequently denied, but if the mapping be done carefully they are shown to exist.

(*c*) On the slate contact there is ore which has inherited the cleavage of the slate. This cleavage has the same orientation as the cleavage of the slate.

(*d*) On the porphyry contact, in the zone of the stockwork, replacement of porphyry has been described in this paper.

(*e*) The Huelva deposits are definitely at the apices of porphyry intrusions and hence if Dr. Rastall's generalization (mentioned above) is correct the ore was brought to the place where it is found, in solution.

As the title of this paper indicates, the mineralogy and petrology are not dealt with. The paper by Professor Bateman contains the fullest description of the mineralogy of the district yet published. The purpose of this paper is to set forth some of the structural facts of the area, for as the late Dr. W. G. Miller said : " The key to the ore-deposits of an area is to be found in the interpretation of the geological structure."

Acknowledgments.

The writer wishes to express his gratitude to Professor J. H. L. Vogt and the management of the Orkla and Sulitelma mines, especially to Mr. Okkenhaug at Orkla and Mr. Carlson, the Chief Mining Engineer, and Mr. Tröflen at Sulitelma.

He is also indebted to Mr. A. O. Brown, the Manager of the Santa Rosa mine, Mr. Hart, the Manager of Tharsis, and Mr. Gray of La Zarza, in the Province of Huelva.

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Geological Studies in the Dublin District: III. Some New Methods in the Study of Rock-jointing.

(Forming with Parts I and II an abridgement of a thesis approved for the Degree of Doctor of Philosophy in the University of London.)

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JOINTING in rocks is a key to the strains and movements they have undergone. In rocks which have had a simple history we expect to find a simple arrangement of joint planes: in old rocks we expect to find evidence of several series of tectonic movements and hence complicated jointing. For example, in the Cambrian quartzite south of Dublin the joint planes appear to run in all directions with no obviously dominant trend. But if say fifty readings taken haphazard in one of the quarries are carefully analysed it becomes evident that the joints tend to lie in certain directions, which, if a graphical method is used, appear as "peaks" on the diagram. On examining other exposures it becomes clear that some of these peaks are of regional significance, for they recur on the diagrams for many or all of the quartzite quarries. The diagrams also show, what is not evident in the field, that in certain directions jointing is almost entirely absent.

Reference has been made in an earlier paper (1) [1] to the jointing in the region around Carrickgollogan. The area now discussed extends from Portrane (Co. Dublin) to the Great Sugar Loaf Mountain (Co. Wicklow) and from the coast to about 10 miles inland. Some 700 joint readings were already available, having been recorded by the late Professor J. P. O'Reilly. (2) His observations are carefully described, and the site of each reading is stated precisely, so that it has been possible to use most of them. More than 1,100 readings have been taken by the present writer, and thus more than 1,800 have been available for analysis.

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[1] Figures in parentheses refer to references at end of paper.

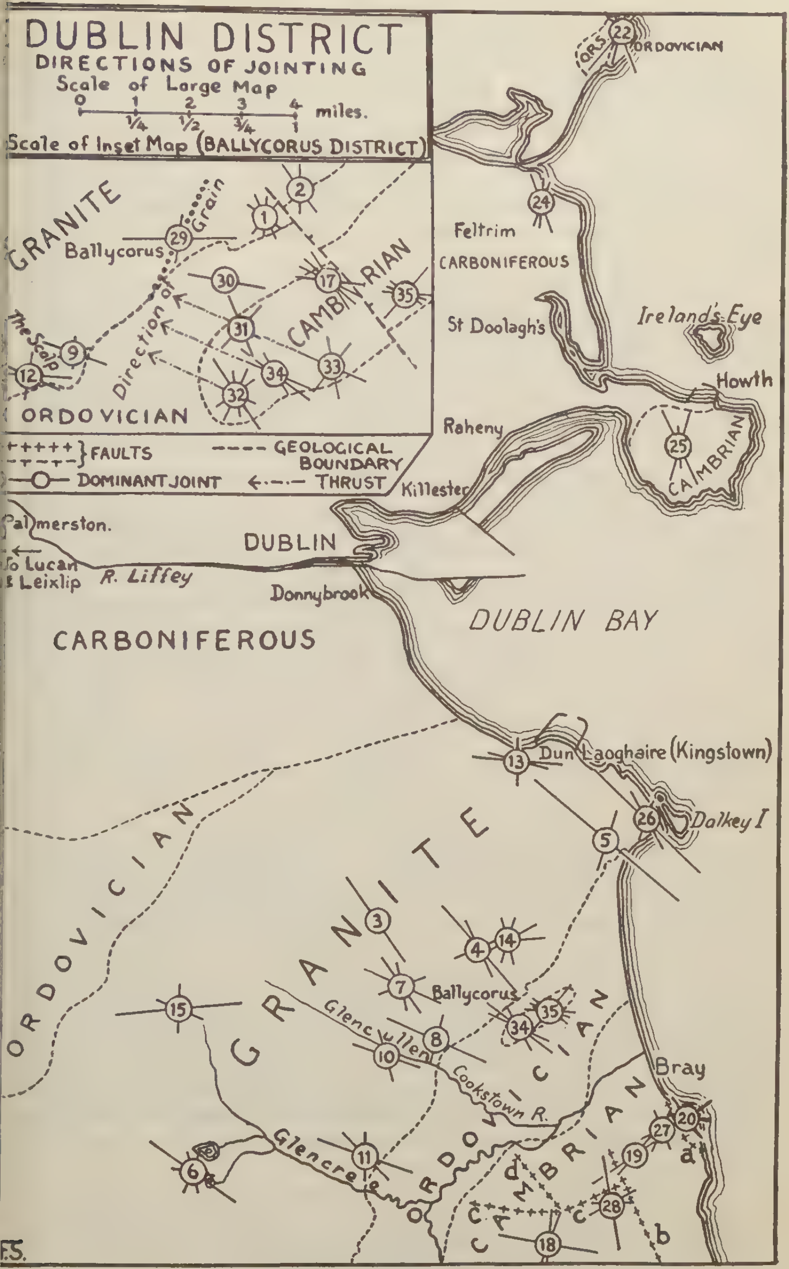

Fig. 1.—For key to localities see Appendix I.

METHOD OF WORKING.

Directions of joints are observed in the field by means of a rule-compass or a prismatic compass. The master joints naturally attract most attention, but minor and apparently accidental joints are not neglected. Horizontal and almost horizontal joints are not included for statistical work, but their occurrence is noted. The observations for each petrological or stratigraphical unit are recorded separately, and further subdivisions are made on a topographical basis.

In summarizing his results O'Reilly made no subdivisions, but took the readings for the whole of the Dublin district *en bloc.* Where a number of readings were approximately the same he counted them and calculated the mean bearing. He thus obtained frequencies for a number of directions placed at irregular intervals. In making use of O'Reilly's readings the present writer has grouped them together in small districts and has calculated frequency values by the method used in connection with his own observations. This method is as follows :—

All directions are expressed according to the trigonometrical convention by stating the number of degrees of turning in a positive (i.e. counter-clockwise) direction necessary to bring a geographical E.-W. line into the observed direction.[1] Thus an E.-W. line is expressed by 0° or 180° ; a N.-S. line by 90° ; a NW.-SE. line by 135°. This system, which will be understood by reference to Diagram A, Fig. 2, must not be confused with the methods very commonly adopted of reading from the geographical or magnetic north in a negative (i.e. clockwise) direction. To express any of the readings in this paper in relation to north it is only necessary to subtract 90° ; e.g. $40° - 90° = -50°$, i.e. 50° east of north, or N.50°E. ; also $120° - 90° = +30°$, i.e. 30° west of north or N.30°W.

To avoid the personal bias which may enter into the selection of groups of readings for the calculation of a mean direction, frequencies are calculated at definite intervals. At first it was thought sufficient to work with intervals of 10°, taking readings 6°–15° as 10°, and 16°–25° as 20°, and so on. Later, using the same interval and taking the readings 0°–9° as 5°, 10°–19° as 15°, and so on, it was possible in some cases to indicate "peak" directions with greater precision ; and by combining these two sets of frequency values the interval is now reduced to 5°. For purposes of comparison it has been found convenient to recalculate the frequency values so that they total 100 ; and since there are 36 frequency values for each set of readings the normal or average frequency value will be 2·78.

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[1] For the convenience of future workers, it is not advisable to record merely the magnetic bearings. Since O'Reilly published his first paper the magnetic declination at Dublin has decreased by about 4 degrees.

To make the method clearer the jointing observed in a group of granite quarries lying to the east of Three Rock Mountain may be taken as an example. The readings actually taken on the compass have been recalculated so as to give the number of degrees as measured from an E.–W. line, and arranged in order :—

1, 3, 7.
17, 18, 19.
22, 23, 28.
33, 36, 38.
43, 43, 47.
75.
90.
100, 100, 101, 103, 108.
113, 115, 117, 119, 119, 119.
120, 122, 122, 123, 125, 125, 125, 125, 125, 126, 129, 129, 129, 129.
130, 132, 134.
149.
154, 157.
162, 165, 166.
174, 175, 176, 177, 179.

Now the joints from 176° to 180° and from 0° to 5° may be taken as E.–W. joints, so that the number of joints approximating to 0° is five (176°, 177°, 179°, 1°, 3°). Similarly the number of joints approximating to 10° (6°–15°) is one (7°); and those approximating to 20° (16°–25°) are five in number (17°, 18°, 19°, 22°, 23°).

Again, the number of joints approximating to 5° (1°–10°) are three in number (1°, 3°, 7°); those approximating to 15° (11°–20°) are three (17°, 18°, 19°); and those approximating to 25° (21°–30°) are also three (22°, 23°, 28°).

The number of readings approximating to the directions 0°, 5°, 10°, 15°, etc., may be set out thus :—

0°	5	
5°		3
10°	1	
15°		3
20°	5	
25°		3
	etc.	

The number of observations made in this district is 56, so that if the above frequency numbers are added together they will give a total of 112. Reducing the values so that they may total 100, 1 becomes 100 ÷ 112 = 0·893, or approximately 0·9 ; 2 becomes 1·8, and so on. The full results are given in Appendix II under the figure 3.

The results may be expressed on a radial diagram or, quite simply, on squared paper as follows : Frequency is plotted vertically ; direction is plotted horizontally measuring from right to left, so that the N.E. quadrant of a jointing system is represented by the right-hand half of the diagram and the N.W. quadrant by the left-hand half, whilst the middle of the diagram corresponds to a N.–S. line. The relation of such a diagram to a radial diagram will be readily understood by reference to Diagrams A and 1 in Fig. 2, both of which represent the jointing of the same district.

Small simplified radial diagrams have been used in the maps in Fig. 1, but in Figs. 2 and 3 tracings from diagrams on squared paper have been used because they have certain advantages.

(i) The ordinary radial diagram tends to become confused at the centre, especially when the lines are drawn at small intervals, and minor features tend to become obscured.

(ii) The eye appears to be less skilful in judging angles than in judging distances, so that slight variations in the directions of joints are more readily detected when rectangular co-ordinates are used.

(iii) When diagrams are drawn with rectangular co-ordinates they may be set in columns, and vertical lines may be drawn to emphasize the constancy of certain features. (Fig. 3.)

It is a well-recognized fact that a set of joints in any particular direction is frequently accompanied by another complementary set lying approximately at right angles to the first. If this were always true we should expect to find that in the ideal jointing diagram the N.E. quadrant is an exact copy of the N.W. quadrant. To estimate how closely this ideal is approached it is only necessary to impose the left-hand half of the diagram upon the right-hand half. Examples are shown in Fig. 4. In some the general agreement between the two graphs is unmistakable, but in others there is wide divergence. This relation may also be tested arithmetically, the complement of any direction being found by adding or subtracting 90°. Thus the complement of a peak at 25° should be found at 115° ; the complement of a peak at 155° should be found at 65°. In actual practice a deviation of 5° from the theoretical position may be ignored.

It is not possible in this paper to give all the data obtained in this investigation. These are given fully in a thesis deposited at the University of London (3). Only part of the tables of frequencies are given here (Appendix II) to indicate the type of results obtained and to include readings from the Portrane district which have been taken since the thesis was written. The series of diagrams, however, are given almost in full (Figs. 2 and 3) and are numbered to correspond to the localities on the map and in the descriptions.

JOINTING IN THE GRANITE.

The jointing in the granite is indicated in diagrams 1 to 16, 26, and 29, in Figs. 2 and 3. Full details of the localities where readings were taken and of the peak directions observed have been recorded elsewhere (3).

In most of the graphs there are conspicuous " peak " directions of jointing but the position of the maximum peak is so variable that when the readings for the whole of the granite are taken together (Fig. 2, Diagram 16) no conspicuous peak remains. It might have been anticipated that granites of similar petrological types would show similar types of jointing, but this is not so. For example, the granites of Dingle Glen and Laughanstown are almost identical as regards their textures and heavy mineral suites. Yet the Laughanstown granite gives a diagram (Fig. 2; 14) which is not at all like that of the Dingle Glen granite (Fig. 2, 4) but bears a strong resemblance to that of the Ballycorus granite (Fig. 3, 29) which differs from it both in texture and heavy mineral content.

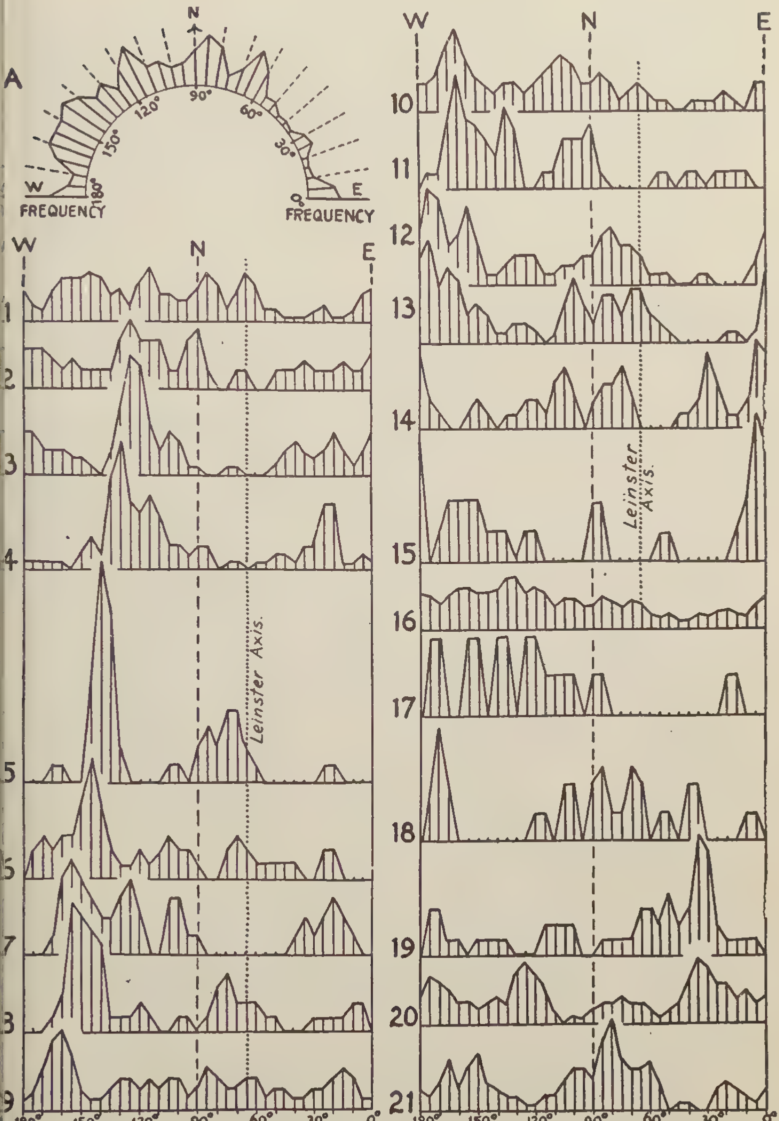

Fig. 2.—Jointing Diagrams. For key to localities see Appendix I.
Horizontal scale: Direction. 0·1 in. represents 10°.
Vertical Scale: Frequency. 0·1 in. represents 2 units of frequency.

In an elongated igneous intrusion such as the Leinster granite, we might expect to observe a series of joints parallel to the axis or margin and a transverse series approximately at right angles to the first. Such a system might be expected to arise as a result of contraction in an elongated cooling mass, or as a result of earth-strains giving rise to an elongated dome. Diagram 16 in Fig. 4 will test this expectation. Here the left-hand half of the jointing diagram has been superimposed upon the right-hand half, so that if the jointing system consists of pairs of joint-directions arranged at right angles to one another the two graphs should show close agreement. There is, however, very little agreement. The only parts of the two graphs which follow the same trend are the peaks at 155°–160° and 65°–70°. Now the axis of the Leinster granite runs approximately N.N.E.–S.S.W., which corresponds to a direction of 67½°. Thus the jointing which was to be anticipated, though not conspicuous, is undoubtedly present.

The directions of aplite and pegmatite veins in the granite should serve to show that joints in certain directions had been formed before the period of igneous activity had closed. Near Dalkey and Killiney these veins are well exposed along the coast, and the directions of many of these are recorded by O'Reilly (2, i). An analysis of his readings show that there is only one peak direction, namely 140°. This is shown (with vertical scale halved) superimposed on the diagram for the Dalkey granite (Fig. 3, 26) with a broken line and dotted shading. Thus the dominant joint-direction (Peaks: *Dalkey* 135°, *Killiney* 140°) was established before the intrusion of the aplites, and it may be concluded that the peak at 120°, observed in the diagram for the Dalkey granite, represents a fissuring which took place at a later period when igneous activity had ceased.

Inland, veins are not well exposed, and observations by the writer do not give conclusive results.

JOINTING IN THE ELVAN.

Observations upon the joints in the elvan have been made at Rathmichael and Shankill, where a number of intrusions occur amongst the schists. In the diagram (Fig. 3, 30) peaks occur at 170°, 155°, 85°. When the left-hand half of the diagram is superimposed upon the right-hand half a certain amount of agreement is observed (Fig. 4, 30).

JOINTING IN THE BRAY SERIES (CAMBRIAN).

Readings were taken at six localities in the quartzites around Carrickgollogan, and results are shown in Diagrams 17 and 31 to 36, in Figures 2 and 3. Full details of the localities and of the peak directions observed have been recorded elsewhere (3).

It will be noticed that a peak at 155° occurs in Diagrams 31, 32, 33, and 34, whilst in Diagram 35 there is a peak at 160°. Taking the quartzites of the Carrickgollogan district as a whole (Fig. 3, Diagram 36) it is seen that the highest peak falls at 155°, whilst other peaks occur at 140°, 100°, 120°, and 50°. The left-hand half of the diagram does not appear to resemble the right-hand half, but if one is superimposed on the other it is seen that the peak at 140° has its complement at 50°, and that the peak at 155° corresponds to a minor peak at 65°–70°.

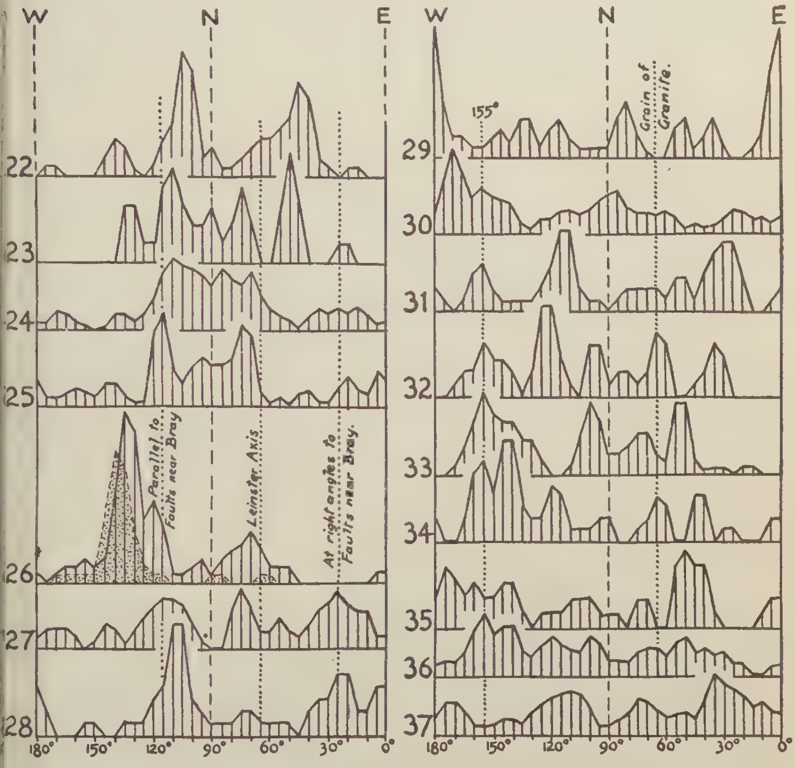

Fig. 3.—Jointing Diagrams. For key to localities see Appendix I.
Horizontal scale: Direction. 0·1 in. represents 10°.
Vertical Scale: Frequency. 0·1 in. represents 2 units of frequency.

The jointing diagrams (18, 19, 20, 27, and 28, Figs. 2 and 3) of the Cambrian quartzites and slates of Bray and its neighbourhood are based upon an analysis of the readings taken by O'Reilly (2, iii).

Taking the Cambrian rocks of Bray and its neighbourhood as a whole (Fig. 3, Diagram 37) it is seen that there is strong jointing in the directions ranging from about 100° to 130°, the peak direction being at 110°. A set of joints complementary to these would appear in the diagram as a peak region ranging from 10° to 40°. This is actually seen in the diagram, although the true peak does not occur at the point (20°) where it would be anticipated. It will be seen in Diagram 37 that the left-hand half of the diagram bears a close resemblance to the right-hand half. In Diagram 27 (Fig. 3) this resemblance is perhaps closer. In Fig. 4 one-half of this diagram has been superimposed upon the other, thus bringing out the striking agreement between the two parts of the graph.

The Cambrian rocks around Bray are affected by a number of faults. The longest fault (marked " b " in Fig. 1) has a trend (as measured on the Geological Survey maps) of about 110°–120°, agreeing closely with peaks in Diagrams 20, 27, 28, and 37. In the diagram for the Lesser Sugar Loaf (Fig. 3, 28) the peaks at 20°–25° also correspond to another fault (" c ") which runs sinuously towards the west (Fig. 1). In the diagram for the Great Sugar Loaf (Fig. 2, 18) there is a peak at 170° closely following the same fault.

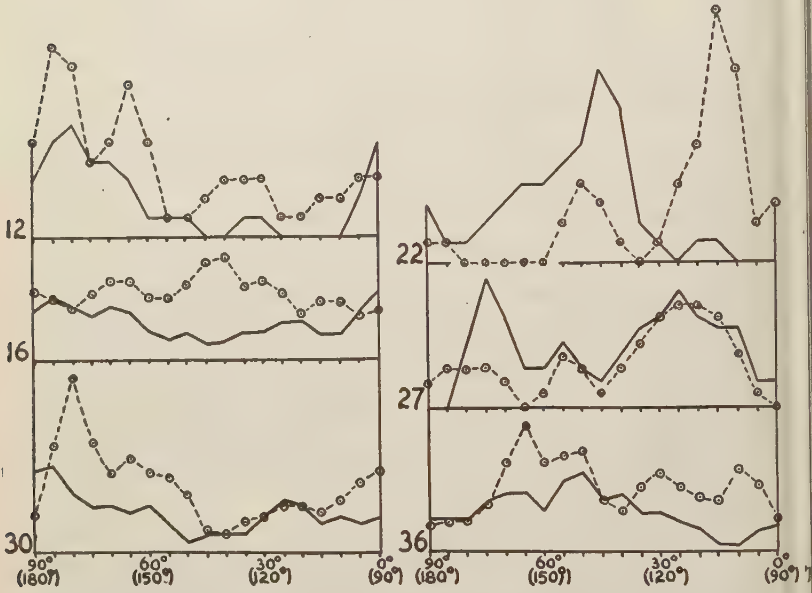

Fig. 4.—Jointing Diagrams. For key to localities see Appendix I. The scale is double that used in Figs. 2 and 3. The unbroken line represents frequency of jointing in directions 0°–90° ; the broken line 90°–180°.

Rocks belonging to the Bray Series also occur on Howth peninsula and on Ireland's Eye. The readings from this district were recorded by O'Reilly (2, i). The results of an examination of his data are shown in Diagram 25 (Fig. 3). The most conspicuous peaks are those at 115° and 75°, whilst there is also a peak at 95°. The directions complementary to these peaks are 25°, 5°, and 165°. Actually there are peaks at 20°, 5°, and 160°.

JOINTING IN THE CARBONIFEROUS ROCKS.

All the readings for the Carboniferous rocks are taken from the papers of O'Reilly (2, ii). The present writer has grouped together the readings of the Malahide district (including Feltrim and St. Doolagh's), obtaining Diagram 24, Fig. 3, and has taken the remaining readings (Dublin and Lucan district), Diagram 21, Fig. 3, as another group. The Malahide diagram resembles that of the Cambrian of Howth (25, Fig. 3) and is quite distinct from the Dublin and Lucan diagram. In general, proceeding inland from the coast the type of jointing changes and joints approximately at right angles to the Leinster axis become more frequent.

PORTRANE.

At Portrane, some 12 miles N.N.E. of Dublin, there occur exposures of red conglomerate, which may be of Devonian age, and of Ordovician rocks—andesites, tuffs, shales, and limestones.

The conglomerate is exposed on the shore E. of the coastguard station, and here twenty-five readings were taken, which on analysis gave peaks at 50°, 110°, and 75° (Diagram 23, Fig. 3).

Farther east the andesite is well exposed, and here fifty readings were taken. The diagram for the andesite shows conspicuous peaks at 105° and 45° (Diagram 22, Fig. 3). The superimposing of the left-hand half of the diagram upon the right-hand half shows that the jointing at 45° is accompanied by an approximately complementary jointing at 140°.

O'Reilly (2, ii) recorded ninety miscellaneous readings along the Donabate coast, from Portrane to Skerries, which on analysis give peaks at 105°, 85°, and 140°.

GENERAL INFERENCES.

The jointing diagrams have so far been considered chiefly in relation to the petrological or stratigraphical division which they represent. The more important results may be summarized as follows:—

Granite.—The diagrams vary widely, but if a small area is taken the diagram is usually simple.

Cambrian.—Even for a small area the diagrams are usually more complex. Some of the peaks are of local occurrence, but others recur with remarkable accuracy in a number of localities. Peaks frequently occur in pairs differing by precisely 90°.

Carboniferous.—In each locality the jointing is usually simple, but tracing the rocks from the coast at Malahide to the exposures around Lucan the type of jointing changes entirely.

It is evident that each system or rock type is not characterized by a definite type of jointing, and it remains to be seen whether a regional consideration of the data leads to more valuable results.

Jointing in the Coastal Region.—Diagrams 22–8 (Fig. 3) represent the jointing of certain localities on or near the coast, arranged in order from North to South. Diagrams 27 and 28 represent two localities in the Cambrian near Bray. In these the most important features are peaks at 115° and 105°–110° (with complementary peaks at 25° and 20°–25°), which it has been shown are related to faults whose general direction may be taken as 115°. This direction is shown by a vertical dotted line on the diagrams, and it will be observed that in every diagram a conspicuous peak occurs within 5° or 10° of this line.

In the granite at Dalkey (Diagram 26) there are well marked joints at 120° which, it has been explained, were formed after the intrusion of the aplite and pegmatite had ceased. On Dalkey Island this trend is rather more conspicuous than at Dalkey itself. The same trend is evident in the outline of the island and in the coastlines and contour lines around Dalkey.

In the diagrams for the Cambrian or Howth (Diagram 25) there is a peak at 115°, and in the very similar diagram for the Carboniferous of Malahide (Diagram 24) there is a peak at 110°, which is also seen in the diagram for the "Old Red" Conglomerate at Portrane (Diagram 23). In the diagram for the andesite at Portrane (Diagram 22) the maximum peak occurs at 105°.

The occurrence in rocks whose ages range from Cambrian to Carboniferous of so many peaks lying near to the direction of the Bray faults can scarcely be accidental. It suggests that *the same strains have affected the whole region from Bray to Portrane and that the movement was, in part at least, post-Carboniferous.* On the present Survey Maps the faults in question are not carried beyond the boundary of the Cambrian rocks.

Jointing around Carrickgollogan.—Reference has already been made in the second part of this paper (1) to the evidence of jointing in relation to the problem of Carrickgollogan. The evidence is presented diagrammatically in the second column of Fig. 3 and in the inset map of Fig. 1.

Diagrams 31 to 34 represent the jointing of the quartzite at separate localities (shown on the inset map) near Carrickgollogan, and Diagram 36 represents the jointing of the whole of the Carrickgollogan quartzites. The most outstanding features are the peaks at 155°. This direction also represents the direction of gliding striae on Carrickgollogan, whilst the complementary direction (65°) is marked by peaks in Diagrams 32, 34, and 36.

Diagram 30 represents the jointing present in the elvan, which is intruded into the schists. It is different from the diagrams either for the quartzite as a whole or for the separate localities. The peak at 155° is still present, but the most pronounced peak lies at 170°. In the diagram for the Ballycorus granite (Diagram 29) the chief peak is at 180° (0°), and there is a pronounced "grain" in the granite, the mean direction of which is 65°, i.e. at right angles to the pronounced joints and gliding striae in the quartzites.

In view of the above evidence the writer has ventured to assume that this (155°) is the direction of the thrusting which was postulated by Cole (4). The direction in which the overthrusting movement probably occurred is indicated in the inset map (Fig. 1) by a series of arrows.

It was also pointed out in the second part of this paper (1) that at Rathmichael (between the numbers 1 and 2 in the inset map) the granite schist junction is crossed by a fault which appears to continue into the area of the Cambrian rocks. The trend of this fault is about 130°. If continued to the N.W. the line would come near to Dingle Glen, where readings have indicated a peak jointing at 130° (Diagram 4, Fig. 2). At Rathmichael East (Fig. 2, Diagram 2) there is a peak at 125°, and in some of the Carrickgollogan diagrams (33, 34 and 36) there are peaks at 120°. If the peaks at 130° and 125° are to be correlated with the fault it might be asked whether the fault may not veer slightly to 120° or 115°, and join the fault "b" in the Bray region.

Glencree.—If the line of the fault marked "c" which affects the Cambrian rocks of the Bray region (Fig. 1) were continued approximately eastward, but veering slightly to the north, it would be found to follow the course of Glencree. At Knockree (indicated in the map by the number 11), a little north of Glencree River, the most pronounced joints (160°) run parallel to this line and to the river. This coincidence, together with the fact that the granite-schist junction as mapped by the Geological Survey (Sheet 121) makes a sharp bend where it crosses Glencree, led the writer to consider the possibility that the glen is a fault-valley marking the continuation of the fault "c". Unfortunately the ground is thickly drift-covered and does not afford exposures to give any definite proof of the existence or non-existence of such a fault.

Glencullen.—If we examine the N.W.–S.E. fault (marked "d" in Fig. 1) in the Sugar Loaf region we notice that if the line were continued towards the N.W. it would follow approximately the course of the Cookstown River from Glencullen Bridge. The river flows from the granite into the Ordovician belt through a gorge which cuts deeply into thick glacial drift. The granite-schist boundary is concealed, but a sweeping bend on the Survey map indicates that the junction is displaced on crossing the river. In the granite quarries at Glencullen Bridge there is strong jointing parallel to the river. On following the granite from the Scalp towards the Cookstown River it is found that the dominant jointing (155°) follows a similar trend. These facts suggest that Glencullen, too, may be a fault valley.

Evidence derived from observations of jointing and from topography suggest that faults in the Bray area may extend into the granite or even across it; but unless the faults can be actually mapped such a view must be put forward with extreme caution. Along the coast faulting at about 115° (25° W. of N.) and inland at about 155° (i.e. at right angles to the Leinster axis) are suggested.

AGES OF FORMATION OF THE JOINTS.

From evidence already presented the age of formation of some of the more constant joints can be deduced with some degree of probability. Part of the succession appears to be as follows :—

(*a*) 140° (N. 50° W.) (Killiney and Dalkey granite).	Early Caledonian (cooling of granite and intrusion of aplites and pegmatites).
(*b*) 155° (N. 65° W.) and 65° (N. 25° E.) (Granite and Cambrian near the granite).	Caledonian overthrusting.
(*c*) 115° (N. 25° W.) (Cambrian, granite, and Carboniferous).	Post-Carboniferous (Armorican ?).

One of the reasons for placing (*c*) after (*a*) has already been given : and in so far as the former occurs in the Carboniferous rocks the necessity of this classification is obvious. The reasons for placing (*b*) after (*a*) are as follows. The joints at 155° are fairly clearly connected with the thrusting movement, which has left signs of strain in the pegmatite and aplite as well as in the granite and elvan. The latter represents a late phase of intrusion and near Carrickgollogan has been mylonized by the movement (2). Clearly (*b*) must be placed before (*c*) unless the Caledonian age of the overthrusting is denied. Cole has given reasons for rejecting the Armorican age of the movement (4, p. 10).

The joints (*c*) were strongly developed only in the coastal region. Further inland the Leinster anticline appears to have continued as a determining factor, so that there is strong jointing in the Carboniferous rocks approximately at right angles to its axis. It is possible that (*c*) is Armorican in age, for it is well known that Armorican features in Ireland do not keep to their usual N.-S. and E.-W. directions but are distorted by the Caledonian grain already imparted to the country.

Little can be said of the pre-Caledonian joints which must exist in the Cambrian rocks, since these joints have been largely obscured by later movement. For example, the diagram for the Cambrian of Howth (Fig. 3, 25) shows only a few minor peaks which are not also seen in the diagram for the Carboniferous of Malahide (Fig. 3, 24).

APPENDIX I. KEY TO LOCALITIES.

A and 1. Rathmichael, W. *Granite.*
2. Rathmichael, E. *Granite.*
3. E. of Three Rock Mt. *Granite.*
4. E. of Dingle Glen. *Granite.*
5. Killiney. *Granite.*
6. Lough Bray. *Granite.*
7. Newtown. *Granite.*
8. Summit W. of Scalp. *Granite.*
9. Scalp, E. *Granite.*
10. Glencullen Br. *Granite.*
11. Knockree. *Granite.*
12. Scalp, W. *Granite.*
13. Kingstown and Blackrock. *Granite.*
14. Laughanstown. *Granite.*
15. Glasamucky. *Granite.*
16. Leinster Granite Total.
17. N.E. of Carrickgollogan. *Cambrian.*
18. Great Sugar Loaf. *Cambrian.*

APPENDIX I (*continued*). KEY TO LOCALITIES.

19. Kilruddery. *Cambrian.*
20. Bray Head. *Cambrian.*
21. Dublin and Lucan District. *Carboniferous.*
22. Portrane. *Andesite.*
23. Portrane. *Devonian.*
24. Malahide. *Carboniferous.*
25. Howth. *Cambrian.*
26. Dalkey. *Granite.*
27. Hillside, nr. Bray. *Cambrian.*
28. Lesser Sugar Loaf. *Cambrian.*
29. Ballycorus. *Granite.*
30. Rathmichael and Shankill. *Elvan.*
31. N.W. of Carrickgollogan. *Cambrian.*
32. W. of Carrickgollogan. *Cambrian.*
33. E. of Carrickgollogan. *Cambrian.*
34. Carrickgollogan. *Cambrian.*
35. S. of Shankill Castle. *Cambrian.*
36. Carrickgollogan and District. *Cambrian.*
37. Bray and District. *Cambrian.*

APPENDIX II. FREQUENCY OF JOINTING.

(For Key to Localities see Appendix I.)

		3	22	23			3	22	23
E.	0°	4·5	—	—	N.	90°	0·9	3·0	6·0
	5°	2·7	—	—		95°	0·9	2·0	4·0
	10°	0·9	—	—		100°	3·6	10·0	4·0
	15°	2·7	1·0	—		105°	4·5	13·0	6·0
	20°	4·5	1·0	2·0		110°	2·7	6·0	10·0
	25°	2·7	—	2·0		115°	5·4	4·0	8·0
	30°	1·8	1·0	—		120°	11·6	1·0	2·0
	35°	2·7	2·0	—		125°	12·5	—	2·0
	40°	3·6	8·0	—		130°	7·1	1·0	6·0
N.E.	45°	2·7	10·0	6·0	N.W.	135°	2·7	3·0	6·0
	50°	0·9	6·0	12·0		140°	—	4·0	—
	55°	—	5·0	6·0		145°	0·9	2·0	—
	60°	—	4·0	—		150°	1·8	—	—
	65°	—	4·0	—		155°	1·8	—	—
	70°	0·9	3·0	4·0		160°	2·7	—	—
	75°	0·9	2·0	8·0		165°	2·7	—	—
	80°	—	1·0	4·0		170°	2·7	1·0	—
	85°	—	1·0	2·0		175°	4·5	1·0	—

REFERENCES.

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(2) O'REILLY, J. P. "On the Directions of Main Lines of Jointing Observable in the Rocks about the Bay of Dublin and their Relation with the Adjacent Coast Lines," parts i, ii, and iii, *Proc. Roy. Irish Acad.*, 1880, vol. iii (2nd series), p. 295; 1884, vol. iv (2nd series), p. 116; 1889, vol. i (3rd series), p. 229.

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Recent Publications.

FOR some years past the Editor of the GEOLOGICAL MAGAZINE has felt considerable uneasiness and regret at the impossibility of according adequate notice to the very large number of memoirs and papers which are sent for review from all parts of the world, many of which contain matter of great interest and importance, such as would be of value to workers in geology if its existence was known to them. This is specially true of geologists who are not within easy reach of a large public library. The Editor has, therefore, decided to try an experiment, taking the form of the occasional publication of a somewhat informal bibliography of such memoirs as they are received. The titles and references will not be stated in strict bibliographic form, such details as number of pages, plates, maps, and figures being usually omitted, but sufficient information will be given to enable the memoir or paper to be referred to, or ordered if it is a separate publication. The items to be included will be for the most part Memoirs of Geological Surveys and other publications of a similar nature rather than individual papers from well-known periodicals, but in this matter some liberty will be exercised. The appearance of a title in this list must not be taken as precluding a review at a later date.

Tanganyika Territory, Geological Survey Department.

Outlines of Geology of the Regions Adjoining the S.E. Shores of Lake Victoria. By F. B. Wade. Short Paper No. 1.
Lupa Gold Field. By D. R. Grantham. Short Paper No. 2.
Kigugwe Copper Deposit, near Brandt's. By G. M. Stockley. Government Printer, Dar-es-Salaam, 1928.
Tanganyika Territory, its Geology and Mineral Resources. By E. O. Teale, *Mining Magazine*, June, July, and August, 1928.

Nyasaland Protectorate, Geological Survey.

The Water Supply Conditions of the Country Traversed by the Proposed Railway Extension from Blantyre to Lake Nyasa. By F. Dixey and C. B. Bissett. Water Supply Paper No. 4.
Weirs, Dams, and Reservoirs for Estate Purposes. By F. Dixey. Water Supply Paper No. 3.
Annual Report of the Geological Survey Department for the year 1928.
Government Printer, Zomba, 1929.

Geological Survey of Southern Rhodesia.

On the formation of Red Soil and of Black Vlei Soil from Dolerite at Salisbury, Southern Rhodesia. By H. B. Maufe. *South African Journal of Science*, vol. xxv, 1928.
Report of the Director for the Year 1928. Salisbury, 1929.
Geological Map of Southern Rhodesia; scale 1 : 1,000,000.

New Zealand, Geological Survey.

The Geology of the Waiapu Subdivision, Raukumara Division. By M. Ongley and E. O. Macpherson.

Federated Malay States, Geological Survey Department.

Report for the year 1928. Supplement to the F.M.S. Government Gazette, 15th March, 1929.

Dominion of Canada, Department of Mines.

Report of the Department of Mines for the year ending 31st March, 1928.

Summary Report, 1927. Part A. Ottawa, 1929.

Fortschritte der Geologie und Palaeontologie.

Band vii, Heft 22. Über Druckschieferung im varistischen Gebirgskörper. By Axel Born.

Band vii, Heft 23. Die varistische Tektonik der mittleren Sudeten. By Erich Bederke.

Berlin, Borntraeger, 1929.

REVIEWS.

An Introduction to the Study of Ore Deposits. By F. H. Hatch. pp. 117, with 31 text-figures. London: George Allen and Unwin, Ltd. 1929. Price 7*s.* 6*d.*

DR. HATCH is well known as a mining geologist of wide experience in many parts of the world: consequently a book written by him is well worth reading, as it represents so largely the results of his own observations. The present volume is, as its name indicates, an *introduction* to the study of ore deposits: therefore it does not profess to give a systematic account of the mine-fields of the world. It is an exposition of principles rather than of details, and consequently all the more valuable, since in so many books on the subject the broader generalities tend to be swamped under a flood of matter of mainly local interest.

The first chapter is founded on a Presidential Address delivered by the author to the Institution of Mining and Metallurgy in 1912, and contains a valuable summary of the history of theories of ore-genesis from the time of Agricola, 1546, to the present day. It may be noted that many of the ideas of the earliest German authors were much more sensible than some that prevailed at a comparatively recent date, when allowance is made for the obscurity of the older language.

The other chapters deal with the different methods of ore-formation according to modern ideas, by magmatic differentiation, pneumatolysis, hydrothermal solutions, and the various types of superficial agencies. Due stress is naturally laid on secondary enrichment in all its manifestations, as well as the different types of ore-concentration by the ordinary geological agencies, resulting in the residual, alluvial, and other deposits which play so important a part in real mining geology, in connection with gold, platinum, tin, and so on. It would appear that Dr. Hatch has at last become a somewhat unwilling convert to the detrital theory of the gold of the Rand Banket; he makes the thoroughly justified reservation that if this gold was alluvial at the time of its deposition it must have been dissolved and reprecipitated in its present form. With this doubtless everyone will now agree.

It is perhaps permissible to note that the term "alluvial", as interpreted by a Mines Department, is not necessarily the same thing as "alluvium" in the geological sense. In the first case it means merely a deposit which can be worked by hydraulic methods, and the reviewer is acquainted with "alluvial" tin deposits in the official sense which are geologically granite in place or ancient sedimentary rocks. It is all a matter of climate and weathering.

The last chapter deals with the forms of ore-deposits. It is obvious that to the miner the shape and extent of the ore-body is really the most important consideration, since on these, given a sufficient metal-content, the life of the mine depends. A full discussion is therefore given of the still somewhat mysterious subject of ore-shoots, as to which it is clear that the last word has not yet been said.

This is a thoroughly practical little book, and its usefulness is enhanced by a very efficient set of indices, including list of authors cited, of minerals, of mines and mining districts mentioned in the text, as well as a general index of subjects. It can be strongly recommended to all those who desire to obtain a preliminary knowledge of its subject.

PRE-DEVONIAN PALAEOZOIC FORMATIONS OF THE CORDILLERAN PROVINCES OF CANADA. By C. D. WALCOTT. Smithsonian Miscellaneous Collections, vol. 75, No. 5, pp. 174–368, pls. 26–108.

AT Dr. Walcott's death this memoir was left in such a form that his associate, Dr. Resser, has been able to prepare it for publication with only such changes as Dr. Walcott himself had intended or would have approved. Thus it embodies Dr. Walcott's latest views on the stratigraphy of the area, and will accordingly be of the greatest value to workers.

It is divided into three parts. The first deals briefly with the unconformity at the base of the Devonian, the folding of the pre-Devonian beds, and the general character of the deposits. The second gives a short description of each of the series into which the succession has been divided. European geologists will regret that Walcott has adopted Ulrich's parochial grouping of the strata into five " systems " instead of the usual three.

The last, and by far the largest, part is devoted to the details of the individual sections. These are described with a fullness and precision that leave nothing to be desired. The position of most of the sections is shown on the map which forms pl. 26. The remaining 82 plates are photographic views, beautifully reproduced, illustrative of the sections.

The whole volume forms an appropriate memorial to its distinguished author and a fitting end to his labours.

REPORTS AND PROCEEDINGS.

GEOLOGISTS' ASSOCIATION.

12*th April*, 1929.

E. J. Wayland : " The Later Geological History of The Equatorial Lakes in Uganda."

Inspection of a map displaying the orientation of Lake Victoria with reference to the Rift Valleys east and west of it suggests genetic relationship. Study of the East Central African area shows that appearances are not deceptive in this respect, and that the great lakes were brought into being by disturbances of (probably) Oligocene date which supervened upon a very long period of tectonic quiescence.

Earth-movements of two kinds have manifested themselves since the inception of the lakes, but the history of these waterways is not to be explained solely by an appeal to tectonics and denudation, and it seems necessary to invoke a third factor, namely, climatic changes. It is not altogether improbable that the latter may be consequent upon the major events of the Ice Age of higher latitudes If this point were established a relative time-correlation could be made between certain lacustrine accumulations and river terraces of Uganda on the one hand, and some Pleistocene and Quaternary deposits of Europe on the other. Facts can be advanced which seem to favour such a correlation, and it is of more than passing interest to observe how stone-age industries, the study of which forms an essential part of the enquiry, fit in with this interpretation.

The history of the lakes (so far as it has been worked out in Uganda) throws light upon the curious distribution of the past and present lacustrine faunas.

CORRESPONDENCE.

DIAMONDS IN SOUTH AFRICA.

Sir,—At Alexander Bay, Cape Colony, where the Orange River flows into the South Atlantic Ocean, diamonds have been found in such profusion as to cast all previous discoveries into the shade. Like all river stones, they excel in quality those found in the mines or " pipes ". The obvious inference is that the diamonds have been transported by the Orange River, especially as it has long been known that its affluent, the Vaal River, contains gravels rich in diamonds, that have been worked during the past sixty years. Although the diamond resists great pressure, a light percussive tap with a hard substance suffices to fracture it. That diamonds should travel together with pebbles over the rocky bed of a river without being shattered may be due to the surrounding water forming a protective cushion. But why are the diamonds concentrated in such abundance at this site ?

A glance at the map of South Africa shows that the northern line of watershed includes a good slice of the Kalahari, it then passes through Lichtenburg in the Transvaal, follows the Witte Water Rand past Johannesburg, and on to Lake Chrissie on the Drakensberg. The eastern line follows the Drakensberg to where the Stormberg branches off. The southern boundary follows the Stormberg, Bamboes Berg, and their continuation to Victoria West, Cape Colony, thence along the Nieuwveldt Range to Kroms Berg, and to the head of the Tanqua River. The western boundary forms an irregular line from the head of the Tanqua River to near the mouth of the Orange River. From the whole of this vast area the water drains into the main channel of the Orange River, and flows westerly to Alexander Bay.

All the South African diamond mines are in " pipes " of extinct volcanoes, or the channels up which molten and fragmentary rocks travelled to reach the craters, when the volcanoes were in action ; there these materials were poured out in lava streams, or hurled out as ash and agglomerate over the surface of the country. Diamonds are distributed through the material filling some of these " pipes " and they must have been plentifully scattered in the volcanic ejectamenta from them. Besides the " pipes " known to bear diamonds and worked, many must exist that have not been discovered.

Such " pipes " are remarkably productive. For example, the Kimberley " pipe " was 12½ acres in area at the surface, diminishing to 7 acres at a depth of 500 feet. From a depth of about 2,000 feet the yield cannot be far short of one hundred millions worth of diamonds.

It is reasonable to conclude that within the river watershed many equally rich " pipes " existed, and that much surface volcanic material was also rich in diamonds.

Wherever worked, these " pipes " are truncated by denuding forces, and their present surface is far below the craters of the once active volcanoes.

The " pipes " are later than the sills and dykes of dolerite, that ramify through the Karroo beds, for they cut through them. At the close of the deposition of the topmost beds of the lacustrine series—the Cave Sandstone—intense volcanic action took place, which piled up two or three thousand feet of volcanic rocks on the top of the Drakensberg. Whether the volcanoes that poured out and hurled out diamonds when the " pipes " were in action were of this date, or later, is uncertain.

Over the whole of South Africa there is abundant and conspicuous evidence of denudation, on a scale that implies the removal of hundreds and even thousands of feet of rock, from above the present surface of the country. A view of the Malutis as they branch from the Drakensberg, or a view southward, from the crest of the Stormberg Range, brings out vividly what has been removed.

When the Cave Sandstone was laid down, it probably extended over the whole area of the lake, as it then existed. To-day but a fragment remains. The difference in level of that fragment (over 6,000 feet above sea-level at the Stormberg) and the present surface of the Karroo series at any site, is a fair measure of what has been denuded, amounting to a vast number of cubic miles of rock, that have been ground to sand and silt, and removed by flowing water for the most part.

With the sandstones, the shales, the dolerite sills, etc., the diamond-bearing surface volcanic rocks and the " pipes " were also worn down, and removed by flowing water. The river conveyed the sand and silt to the sea. Diamonds dispersed through the surface volcanic rocks, and though the " pipes ", however, were not ground up, but survived intact, owing to their hardness. Unlike gold and other metallic substances, they were easily removed by water, and transported by that medium. They found their way into runnels and tributaries of the Orange River, eventually reaching the sea at its mouth. Owing to their sp. gr. being somewhat higher than quartz and felspar, a certain amount of concentration took place.

The sea appears to have exercised a selective action on the diamonds, and perhaps owing to their form the waves have cast them up on shore again. Along the west coast of South Africa the set of the current is northward. Small diamonds appear to have been carried by the current for a considerable distance, along the shores of Namaqualand. Both sand and diamonds were blown from the beach inland to form sand-dunes.

Given the vast area drained by this river, the presence over this area of numerous diamond-bearing " pipes " and ejectamenta from them, the stupendous denudation that has taken place over this area, from the time the mountains of volcanic matter were piled up on the top of the Drakensberg, to the present day, and that the imperishable diamonds in the material removed by denudation have eventually reached and travelled down the main channel of the Orange River, and been concentrated where it enters the sea; their abundance at Alexander Bay is accounted for.

In December, 1871, the writer spent a day at Alexander Bay and noticed the pink garnet sand on the beach, but did not see the diamonds.

In 1872 he travelled through Bushmanland and touched on the course of the Orange River at various points. Below Aughrabies Falls, or the Great Falls, the river flows for 3 or 4 miles through a great gorge it has cut out in hard gneiss, 300 feet below the general level of the country. At these falls there are many potholes; some are 12 feet or more in diameter, and proportionately deep, and have been ground out by the swirling waters and the pebbles. As a small pothole at Alexander Bay has produced £40,000 worth of magnificent diamonds, what may be expected when these and crevices in the rocky bed of the river are exploited? Unless great floods have swept the channel clean. This river flows over a rocky floor for hundreds of miles, in fact, from Hope Town to the sea.

Besides Orange River, it is known as the Gariep, the Groot River, etc., but it deserves to be called the River of Diamonds.

E. J. Dunn.

"Roseneath,"
Kew, Victoria,
Australia.

The Editor regrets that by an oversight the price of Messrs. Murby's patterns for making geological block models was stated in the May number as 4*s.* per set; this should have been 1*s.* 6*d.*